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A Comparison of Muscle Recruitment Across Three Straight-Legged, Hinge-Pattern Resistance Training Exercises

JEREMY R. DICUS‡1, SAMUEL H. ELLESTAD*1, JESSE E. SHEAFFER*1, CAROL A. WEBER*1, NOAH C. NOVAK*1, and MICHAEL E. HOLMSTRUP‡1

[1]Department of Exercise Science and Athletic Training, Slippery Rock University, Slippery Rock, PA, USA

*Denotes undergraduate student author, †Denotes graduate student author, ‡Denotes professional author

ABSTRACT

International Journal of Exercise Science 16(4): 12-22, 2023. Hinge exercises are critical to building a balanced resistance training program in concert with 'knee-dominant' (e.g., squat, lunge) exercises. Biomechanical differences between various straight-legged hinge (SLH) exercises may alter muscle activation. For example, a Romanian deadlift (RDL) is a closed-chain SLH, while a reverse hyperextension (RH) is open-chain. Likewise, the RDL offers resistance via gravity while the cable pull-through (CP) offers redirected-resistance through a pulley. A deeper understanding of the potential impact of these biomechanical differences between these exercises may improve their application to specific goals. Participants completed repetition-maximum (RM) testing on the RDL, RH, and CP. On a follow-up visit, surface electromyography of the longissimus, multifidus, gluteus maximus, semitendinosus, and biceps femoris, muscles that contribute to lumbar/hip extension, was recorded. After a warm-up, participants completed maximal voluntary isometric contractions (MVICs) in each muscle. They then completed five repetitions of the RDL, RH, and CP at 50% of estimated one RM. Testing order was randomized. A one-way, repeated-measures ANOVA test was used in each muscle to compare activation (%MVIC) across the three exercises. Shifting from a gravity- (RDL) to a redirected-resistance (CP) SLH significantly decreased activation in the longissimus (-11.0%), multifidus (-14.1%), biceps femoris (-13.1%), and semitendinosus (-6.8%). Alternately, changing from a closed- (RDL) to an open-chain (RH) SLH significantly increased activation in the gluteus maximus (+19.5%), biceps femoris (+27.9%), and semitendinosus (+18.2). Alterations in the execution of a SLH can change muscle activation in lumbar/hip extensors.

KEY WORDS: Muscle activation, reverse hyperextension, Romanian deadlift, cable pull-through

INTRODUCTION

Hinge-pattern resistance training exercises (i.e., hinge exercises) are lower-body movements that prioritize eccentric hip flexion and concentric hip extension. These exercises may be utilized in concert with squat-pattern exercises, which tend to have a more equal balance between both knee- and hip-involvement, to stress both anterior and posterior chain muscle groups. Despite the importance of hinge exercises in a well-balanced resistance training program, many studies have compared hinge- to squat-pattern exercises or compared variations of exercise within the squat pattern (1, 6, 18, 23). For example, recent work by Bautista and colleagues comparing muscle activation between the front squat and the overhead squat was able to observe differences in leg, back, core, and shoulder muscle activation (1).

Much like the squat-pattern, hinge-pattern exercises vary in form and are often grouped into two main categories, that of 'bent-knee' hinges and 'straight-legged' hinges. Bent-knee hinges involve a greater degree of knee flexion throughout the exercises than the straight-legged hinges (SLH), which tend to keep the knee in a 'soft' (i.e., slightly flexed, but consistent) position. Some examples of bent-knee hinges include the glute bridge and hip thrust, while straight-legged hinge exercises include the Romanian deadlift (RDL) (Figure 1a-b), reverse hyperextension (RH) (Figure 2a-b), and cable pull-through (CP) (Figure 3a-b). These variations in hinge-pattern exercise form can therefore lead to differences in muscle activation between exercises.

Figure 1a and 1b. Demonstration of the top and bottom position for the Romanian Dead Lift

Figure 2a and 2b. Demonstration of the top and bottom position for the Reverse Hyperextension

Figure 3a and 3b. Demonstration of the top and bottom position for the Cable Pull-through

Hinge-pattern exercises with a distinct conceptual difference (i.e., closed chain v. open chain; gravity-directed v. pulley-redirected resistance) and their associated muscle activity have been examined in prior literature. McAllister and colleagues analyzed variations in the activation of the hamstring, erector spinae, and gluteus medius muscles during concentric and eccentric contractions using 'good mornings' and 'glute-ham raises', closed and open kinetic chain hinges, respectively (17). Similarly, Delgado and colleagues analyzed variations in the muscle activation of the gluteus maximus, biceps femoris, and vastus lateralis during the Romanian deadlift and barbell hip thrust, straight-legged and bent-knee hinges, respectively (6). Other variables, including the influence of joint and rotation angles on muscle activity in the posterior chain muscles, have also been previously researched (12, 15).

By distinguishing what makes different exercises unique, strength/conditioning and rehabilitation professionals can better apply the exercises to the appropriate populations. Along these lines, Vigotsky, Contreras, and Beardsley have likened the alignment of muscle activation specificity using exercise variations as a means of optimizing functional activities, to produce the greatest performance gains (22). To expand on previous research into the hinge pattern, (3, 6, 12, 17) a specific examination into how the differences between various straight-legged hinge exercises target musculature of the lower body may further improve training specificity and application. Improvements in the application of SLH exercises may allow clinicians to accurately prescribe them as a means of injury prevention and rehabilitation (15). Similarly, further improvements in the knowledge base regarding the application of SLH exercises may improve the specificity of their use by strength and conditioning professionals.

The purpose of this study was to examine muscle activation in select posterior chain muscles during three SLH exercises in apparently healthy, young males. Changes in the kinetic chain (i.e., closed chain v. open chain) and direction of resistance (i.e., gravity-directed v. pulley-redirected resistance), or combinations of both, were identified as common variations that could be altered to improve practical application in rehabilitation and strength and conditioning settings. Specifically, the RDL and RH were compared as examples of closed- and open-chain hinge variants, the RDL and CP as a gravity-directed v. a pulley-redirected hinge variant, and the RH was compared to the CP as open-chain, gravity-directed resistance hinge variants v. closed-chain and pulley-redirected hinge variants, respectively. Based on these variations, it was hypothesized that muscles would demonstrate different levels of EMG activation across the RDL, RH, and CP.

METHODS

Participants

This research was carried out fully in accordance to the ethical standards of the International Journal of Exercise Science (19). This study was approved by the Slippery Rock University Institutional Review Board. Prior to participation, individuals read the informed consent document and signed when their questions were satisfied. Apparently healthy, college-aged males volunteered to participate in this study. To participate, individuals were required: 1) to have taken an upper-level university course that taught the safe execution of resistance training exercise, and 2) to have the capability to perform safe hinge-pattern movements. Further, prior hip, knee, and ankle health was recorded via a health history and demographic survey prior to participation. To determine minimum adequate sample size, an a priori power analysis was conducted (G*power V 3.1.9.4). A previous study by McAllister and colleagues comparing muscle activity across four hamstring exercises reported effect size values ranging from 1.5 to 2.7 (17). With this information, a conservative estimate of effect size was used to determine minimum adequate sample size. The following parameters revealed the need for a sample of 9 subjects to reach adequate power: F test, repeated measures ANOVA (within factors), effect size 0.5, $\alpha = 0.05$, $1-\beta = 0.8$.

Protocol

Each participant attended two data collection sessions. During the initial session, participants completed the health history form and denoted the completion of the upper-level resistance training course. Body composition was assessed using a medical body composition analyzer (SECA mBCA, Chino, CA, USA) to determine weight, fat-free mass (kg), and body fat percentage (%). Following a five-minute aerobic warm-up on a treadmill at a self-selected speed, each participant completed a series of standard dynamic warm-up drills. This included 20-meter high-knees, butt-kicks, Frankensteins, inside-to-outside marches, outside-to-inside marches, and body weight lunges. Participants then established a three to five repetition maximum (RM) on the RDL (plate-loaded barbell), RH (plate-loaded pendulum machine), and CP (selectorized cable machine) exercises. The three to five RM was used to calculate a predicted one-RM (10). The investigators then calculated 50% of the predicted one-RM for use during session two of data collection. Prior to completing the initial session, participants were advised not to participate in any lower body resistance training in the forty-eight hours prior to their second testing session.

For the second session, participants practiced all three hinge movements with no resistance until both technique and pace were performed to an acceptable degree for further analysis. Participants then completed the same warm-up described for the initial data collection session.

Participants were then prepared for surface electromyography (Mini DTS, Noraxon, 15770 N Greenway Hayden Loop #100, Scottsdale, AZ 85260) at the longissimus (LT), multifidus (MF), gluteus maximus (GM), biceps femoris (BF), and semitendinosus (ST) using standard shaving, abrading, and cleaning procedures. Dual EMG Ag/AgCl electrodes with an interelectrode distance of 2cm, were placed over the LT, MF, GM, BF, and ST at previously reported measurement sites provided by the SENIAM group (11). Specifically, the LT sensor was placed vertically, two finger widths (3-4cm) lateral to the spinous process of the first lumbar vertebrae (11). The MF sensor was placed 2-3cm lateral to the fifth lumbar vertebrae, diagonally from the posterior-superior iliac spine to the first lumbar vertebrae (11). The GM sensor was placed in line with the posterior superior iliac spine and the posterior thigh at a point 50% of the distance from the second sacral vertebrae to the greater trochanter (11). The BF sensor was placed at a point 50% of the distance between the ischial tuberosity and the lateral epicondyle of the tibia (11). The ST sensor was placed at a point 50% of the distance between the ischial tuberosity and medial epicondyle of the tibia (11). For consistency of measurement in these bilateral exercises, all EMG electrodes were placed by the same researcher on the participants' right side. Additionally, each participant was instrumented with a Noraxon lower-body inertial measurement unit (IMU) setup that allowed measurement of hip flexion and extension. Using Noraxon's MyoMOTION Research Pro software, delineation of the concentric and eccentric phases of movement were determined based on change in direction.

EMG data were normalized via the use of previously reported maximal voluntary isometric contraction and break test protocols for the LT, MF, GM, BF, and ST (4, 7, 8, 20). The break test for the LT and MF was completed by having the participant lie prone with their forehead resting flat on the table and their hands behind their head. The participant's feet were held down while they extended the trunk to lift their chest off the table. This was designated as the starting position. Increasing resistance was then applied in a downward direction on the participant's upper back until they could no longer hold the start position. The break test for the GM was performed with the participant prone with the knee at 90 degrees of flexion. The participant was then instructed to lift their thigh off the table to go into hip extension. This was designated as the starting position. Increasing pressure was then applied to the posterior femur until they could no longer hold the starting position. The break test for the BF and ST was completed with the knee at 90 degrees of flexion while the participant was prone. This was designated as the starting position. Increasing resistance was then applied to the posterior, distal tibia pulling the knee away from their body until they could no longer hold the start position. The break tests for the GM, BF, and ST were all conducted on the participants' right side. EMG data from this study are reported as a percentage of the peak activity measured during the break testing procedures.

Following EMG preparation, participants were instructed to perform five repetitions of each hinge exercise at the calculated 50% of predicted one-RM load from session one. Exercise order during session one and session two was randomized. Each repetition was observed from the sagittal plane by a trained research assistant to assess proper exercise technique and ensure the safety of the participant. When engaging in the RDL and CP exercises, participants maintained a standardized 2-0-2 pace with a two-second eccentric phase followed by a two-second concentric phase. Participants followed the same 2-0-2 pace when completing the RH, except that the movement began with the concentric phase. A metronome set to 60bpm assisted the participants with maintaining the 2-0-2 pace.

Surface EMG of the LT, MF, GM, BF, ST, and was sampled at a rate of 1000 Hz using the Noraxon Mini DTS EMG system (Noraxon, 15770 N Greenway Hayden Loop #100, Scottsdale, AZ 85260). EMG signal processing was performed with MyoResearch 3 version 3.16.96 (Noraxon, 15770 N Greenway Hayden Loop #100, Scottsdale, AZ 85260).).

Statistical Analysis

Prior to statistical analysis, raw EMG data were amplified, band-pass filtered (20 and 450 Hz), rectified and smoothed using a root mean squared (RMS) integration of 100ms. Each participant's filtered EMG data were normalized via the MVIC procedures described above. A one-way analysis of variance test with repeated measures was performed on the average RMS EMG values for the total, concentric, and eccentric phases for the LT, MF, GM, BF, and ST muscles (main effects reported as significance, F statistic, and effect size). RMS values for the middle three repetitions of each exercise were recorded and averaged for use in the analysis. A Bonferroni post hoc test was employed on all measures where a main effect was detected (reported as value, adjusted *p*-value, and 95% confidence interval). An *a-priori* significance value of .05 was established. All data were analyzed using GraphPad Prism 9.3.1 for Windows (GraphPad Software, San Diego, CA, USA).

RESULTS

Twelve male participants completed all requirements of the study. The average age for the cohort was 20.8 ± 0.2 years (Table 1). The average participant height was 177.8 ± 2.1cm and average weight was 75 ± 2.2kg (Table 1). Overall, this placed the cohort towards the top of the healthy BMI range (24.8 ± 0.3kg/m2) (Table 1). The average body fat percentage was 13.9 ± 1.2% and individuals averaged 28.1 ± 3.1kg of skeletal muscle mass (Table 1). None of the participants reported any pertinent musculoskeletal injuries or conditions on the health history.

Table 1. Demographic History

Characteristic	Males (*n* = 12)
Age (years)	20.8 ± 0.2
Weight (kg)	78.5 ± 2.2
Body Mass Index (kg/m^2)	24.8 ± 0.3
Body Fat Percentage (%)	13.9 ± 1.2
Skeletal Muscle Mass (kg)	28.1 ± 3.1

All values reported as mean ± standard error of the mean.

Main effects were found in the LT (p = .005; F (1.411, 15.52) = 8.837; $r2$ = 0.4455), MF (p < .001; F (1.646, 18.10) = 16.18; $r2$ = 0.5953), GM (p = .013; F (1.309, 14.40) = 7.099; $r2$ = 0.3922), BF (p < .001; F (1.368, 15.05) = 32.02; $r2$ = 0.7443), and ST (p = .001; F (1.125, 12.38) = 15.85; $r2$ = 0.5654) muscles.

Higher EMG activity was observed in three of the five measured muscles when the RH was compared to the RDL. Specifically, significantly greater EMG activity was measured in the BF (62 v. 35%; p = .002; -44.52 to -11.11), GM (49 v. 30%; p = .044; -38.57 to -0.5243), and ST (49 v. 31%; p = .017; -33.20 to -3.256) muscles when performing the RH compared to the RDL, respectively (Table 2). Exploring the concentric and eccentric phases of the exercise revealed greater EMG activity during the eccentric phase of the RH when compared to the RDL. Post hoc analysis revealed significant increases in eccentric EMG activity of the GM (36 v. 20%; p = .011; -27.92 to -3.611), BF (56 v. 24%; p = .007; -55.22 to -8.882), and ST (44 v. 22%; p = .047; -43.85 to -0.2387) when comparing the RH to the RDL, respectively (Table 2).

Higher EMG activity was observed in four of the five measured muscles when the RDL was compared to the CP. Specifically, significantly greater EMG activity of the LT (57 v. 46%; p = .001; -19.56 to -2.442), MF (61 v. 47%; p = .005; -23.85 to -4.325), BF (35 v. 21%; p = .002; -44.52 to -11.11), and ST (31 v. 24%; p = .005; -11.43 to -2.200) was measured when performing the RDL compared to the CP, respectively (Table 2). When examining the concentric phase, significantly greater EMG activation was noted in the LT (69 v. 57%; p = .047; -24.50 to -0.1299), MF (76 v. 57%; p = .014; -34.03 to -3.754), BF (52 v. 33%; p = .001; -31.45 to -8.684), and ST (46 v. 36%; p = .003; -15.54 to -3.498) in the RDL than the CP, respectively (Table 2). In the eccentric phase, a similar discrepancy in EMG activation, wherein the RDL revealed greater activation than the CP, was noted in the LT (49 v. 37%; p = .008; -20.71 to -3.168), MF (52 v. 40%; p = .004; -20.37 to -4.010), BF (24 v. 13%; p = .009; -18.46 to -2.657), and ST (22 v. 16%; p = .026; -11.68 to -0.7319), (Table 2).

Finally, greater EMG activity was observed in four of the five measured muscles when the RH was compared to the CP. Specifically, significantly greater EMG activity of the, LT (67 v. 46%; p = .015; -37.79 to -4.033), MF (73 v. 47%; p = .002; -40.65 to -10.63), BF (62 v. 21%; p < .001; -58.42 to -23.58), and ST (49 v. 24%; p = .003; -41.15 to -8.94) was measured when performing the RH compared to the CP, respectively (Table 2). When examining the concentric phase, significantly greater EMG activation was also noted in the, LT (82 v. 57%; p = .009; -42.95 to -6.485), MF (90 v. 57%; p = .002; -53.37 to -12.37), BF (71 v. 33%; p < .001; -56.59 to -19.96), and ST (57 v. 36%; p = .014; -37.73 to -4.224) in the RH than the CP, respectively (Table 2). In the eccentric phase, a similar discrepancy in EMG activation, wherein the RH revealed greater activation than the CP, was noted in the MF (59 v. 40%; p = .042; -37.43 to -0.674), GM (36 v. 20%; p = .032; -31.27 to -1.345), BF (56 v. 13%; p < .001; -64.24 to -20.98), and ST (44 v. 16%; p = .015; -51.12 to -5.392) muscles (Table 2).

Table 2. Comparison of muscle activation between straight-legged hinge variants

Muscle Activation (%MVIC)		Pullthrough	RDL	Reverse Hyper
Longissimus	Total	45.7 ± 3.2[bc]	56.7 ± 3.8[a]	66.6 ± 4.4[a]
	Concentric	56.9 ± 4.2 [bc]	69.2 ± 5.9[a]	81.6 ± 5.9[a]
	Eccentric	37.2 ± 3.2[b]	49.2 ± 3.8[a]	54.6 ± 6.0
Multifidus	Total	47.1 ± 2.3[bc]	61.2 ± 3.5[a]	72.8 ± 4.6[a]
	Concentric	56.6 ± 2.4[bc]	75.5 ± 6.0[a]	89.8 ± 7.2[a]
	Eccentric	40.0 ± 2.7[bc]	52.2 ± 3.2[a]	59.0 ± 5.1[a]
Gluteus Maximus	Total	28.6 ± 4.0	29.6 ± 5.0[c]	49.1 ± 5.8[b]
	Concentric	39.5 ± 5.2	44.3 ± 7.6	64.3 ± 9.5
	Eccentric	20.0 ± 3.7[c]	20.6 ± 3.4[c]	36.3 ± 4.1[ab]
Biceps Femoris	Total	21.4 ± 2.2[bc]	34.5 ± 4.2[ac]	62.4 ± 6.5[ab]
	Concentric	32.5 ± 3.2[bc]	52.6 ± 5.4[a]	70.8 ± 7.0[a]
	Eccentric	12.9 ± 1.8[bc]	23.5 ± 3.5[ac]	55.6 ± 8.1[ab]
Semitendinosus	Total	24.4 ± 3.2[bc]	31.2 ± 4.2[ac]	49.4 ± 7.8[ab]
	Concentric	36.1 ± 5.3[bc]	45.6 ± 6.7[a]	57.1 ± 8.9[a]
	Eccentric	15.6 ± 1.9[bc]	21.8 ± 2.7[ac]	43.8 ± 9.5[ab]

All values reported as mean ± standard error of the mean. [a]Different from Pullthrough. [b]Different from RDL. [c]Different from Reverse Hyper. $P < 0.05$.

DISCUSSION

There were three main findings in the present study. First, there was increased muscle activation in the LT, MF, BF and ST when comparing a gravity-directed SLH to a pulley-redirected SLH at the same percentage of maximal effort. There was no significant difference in gluteus maximus activation between the gravity-directed SLH and the pulley-redirected SLH. Second, muscle activity was greater in the GM, BF, and ST when comparing an open chain SLH to a closed chain SLH at the same percentage of maximal effort. There were no significant differences in muscle activation of the trunk muscles (i.e., LT and MF) when compared between the RH and the RDL. Third, muscle activity was greater in the LT, MF, BF and ST when comparing the open-chain and gravity-directed hinge variant to the closed-chain and pulley-redirected hinge variant. There was no significant difference in GM activation between the RH and the CP.

EMG activity for the GM, BF, and ST was significantly greater in the RH compared to the RDL. While the authors are unaware of any research that has compared these two exercises previously, Lawrence and colleagues (13) did compare the RH to the traditional hyperextension (HE) and found that there was greater muscle activity in the erector spinae (ES), GM, and BF during the HE than the RH. Contrary to the findings of Lawrence et al, (13) Cuthbert and colleagues (5) found that a greater muscle activation during the RH compared to the HE in the GM, BF, and ST. Both Cuthbert et al (5) and Lawrence et al (13) standardized the workload for their experiments by basing on a percentage of participant body weight. It is important to note, the present study calculated the work load from a predicted one-RM.

Unlike the RH and CP, muscle activation of the RDL has been compared to other exercise variants in several different studies (2, 6, 14, 16, 17, 20). For example, Lee and colleagues compared the EMG activation of the RDL to the conventional deadlift (DL) and found increased activation of the GM and BF during the DL (14). Conversely, Bezerra and colleagues compared the stiff legged deadlift (SLDL), a similar exercise to the RDL initiated from the floor, to the DL (2). They observed no statistical differences in MF and BF activation between the SLDL and the DL (2). This differs from the present study which compared two closed chain exercises (RDL v. CP) and, observed significantly greater muscle activation in both MF and BF, in favor of the RDL. Muscle activity during the RDL has also been compared to the prone leg curl, good morning, and glute-ham raise (GHR) exercises (17). McAllister and colleagues showed that the ST was less active in the RDL compared to the good morning and GHR, while the BF produced similar activity during the RDL and prone leg curl (17).

The comparison of concentric and eccentric muscle activation is not common in the literature studying hinge exercises, but may shed light on how SLH's could be applied in strength/conditioning settings. A systematic review conducted by Martin-Fuentes and colleagues examined nineteen different studies that investigated the muscle activation of different deadlift variations, only seven of which divided EMG activity into concentric and eccentric phases (16). Of those studies, all seven showed greater muscle activation in the concentric phase compared to the eccentric phase (16). Our findings align directly with this literature as the concentric phase of the RDL, RH, and CP all resulted in greater muscle activation compared to their eccentric phases. Similar results have also been observed when comparing variations of the pull-up exercise (7). These similar findings are likely because concentric contractions, compared to eccentric contractions, require greater levels of force production, and subsequently display greater activation (9). Interestingly, in the present study, the GM was observed to have significantly greater activation in the eccentric phase of the RH when compared to both RDL and CP. However, no difference in muscle activation of the GM was observed during the concentric phase across the three exercises. It is likely that the long moment arm of the RH influenced the increase in mean activation of 16-20% in the GM over the RDL and CP.

The present study does have limitations which should be considered when examining results. The participant sample for this study was comprised of college aged males with training in the safe and effective implementation of resistance training exercise. As such, caution should be taken when attempting to generalize results to a broader population. With participant safety in mind, a relatively low workload (50% estimated one-RM) was calculated and used for this study. This lower workload is typically used for endurance training. As previously stated, the workload was calculated from a three to five RM and this in itself proved to be a limitation of the study. Participants reported difficulty accurately determining a three to five RM in the RH and CP. This was due to a lack of familiarity with the exercise (CP and RH) and limitations of the equipment (CP). Finally, the present study standardized the pace of movement (2-0-2) which limits the potential breadth of application for the findings of this study.

To the authors' knowledge, this is the first study to compare muscle activity across the RDL, RH, and CP SLH movements. Primary findings suggest that the RH may be better suited to activate the hip extensors compared to the RDL and the CP, whereas both the RH and the RDL are better poised to activate the lumbar extensors compared to the CP. From these findings, we conclude that individuals looking to prioritize activation of the hip extensors, may choose to utilize the RH exercise, and individuals looking to activate the lumbar extensors could adequately do so via either the RH or the RDL. Future studies looking to assess the capacity for strength or hypertrophy development using these SLH exercises may utilize our findings as a start point.

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