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A Comparison of Gluteus Maximus, Biceps Femoris, and Vastus Lateralis EMG Activity in the Back Squat and Barbell Hip Thrust Exercises

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ABSTRACT (200 words)

The back squat and barbell hip thrust are both popular exercises used to target the lower body musculature; however, these exercises have yet to be compared. Therefore, the purpose of this study was to compare the surface electromyographic (EMG) activity of the upper and lower gluteus maximus, biceps femoris, and vastus lateralis between the back squat and barbell hip thrust. Thirteen trained women (n = 13; age = 28.9 years; height = 164 cm; mass = 58.2 kg) performed estimated ten-repetition maximums in the back squat and barbell hip thrust. The barbell hip thrust elicited significantly greater mean (69.5 vs. 29.4%) and peak (172 vs. 84.9%) upper gluteus maximus, mean (86.8 vs. 45.4%) and peak (216 vs. 130%) lower gluteus maximus, and mean (40.8 vs. 14.9%) and peak (86.9 vs. 37.5%) biceps femoris EMG activity than the back squat. There were no significant differences in mean (99.5 vs. 110%) or peak (216 vs. 244%) vastus lateralis EMG activity. The barbell hip thrust activates the gluteus maximus and biceps femoris to a greater degree than the back squat when using estimated 10RM loads. Longitudinal training studies are needed to determine if this enhanced activation correlates with increased strength, hypertrophy and performance.

Key Words: back squat, hip thrust, gluteus maximus, electromyography, gluteus maximus EMG

Word Count: 3,877

INTRODUCTION

The gluteus maximus is considered to be important for both sports performance and injury prevention due to its multiplanar contribution to high-speed locomotion and knee stabilization.[1-4] Therefore, strength coaches commonly employ exercises to strengthen the gluteus maximus musculature of their athletes.[5-9] Two frequently prescribed exercises for strengthening the gluteus maximus are the back squat and barbell hip thrust.

The knee extensors have been shown to be the largest contributors (49%) to vertical jump performance,[10] while hip extensor and knee flexor muscles have been shown to increase the most in relative muscle force contribution as running speed progresses towards maximum.[3,11] Therefore, the quadriceps and hamstrings also are of great importance for maximizing performance in sports that are reliant upon running prowess.

The back squat is perhaps the one of the most studied and utilized closed kinetic chain exercise and is a staple in strength and conditioning programs aimed at strengthening both the lower body in general and the gluteus maximus in particular. Numerous studies have investigated gluteus maximus electromyography (EMG) activity in the back squat, as reported in a recent review.[12] The researchers found that increasing stance width and hip rotation in the back squat led to increased gluteus maximus and adductor activity, that back squat depth past parallel doesn't significantly alter muscle activity assuming identical relative loading is used, that leg and trunk muscle activity increase with increasing load, and that the highest muscle activation occurs in the initial portion of the concentric phase of movement.

However, there is a paucity of data comparing gluteus maximus EMG activity in the back squat to other barbell exercises that target this muscle.[12] The back squat is also commonly used in strength and conditioning programs for increasing sprint running ability. Its usage for this purpose is supported by a recent meta-analysis in which the back squat was shown to transfer positively to sprint running performance.[13] However, large increases (~23-27%) in back squat 1 repetition maximum (RM) are necessary for significant changes in sprint times (~ –2-3%) in recreationally trained athletes and collegiate football players.[14,15] Given this relatively low transfer effect, it is of interest for sports science researchers to understand the best exercises, methods and protocols for improving sprint running performance. Since the gluteus maximus and hamstrings are highly activated in sprinting,[3,16-19] it would be reasonable to assume that exercises that activate the gluteus maximus and hamstrings to a greater degree than other exercises may be better suited for increasing the strength of those muscles and thus, sprinting speed.

The barbell hip thrust, first introduced in the literature by Contreras and colleagues[20], is another exercise aimed at strengthening the gluteal musculature. To date, no acute or longitudinal studies have investigated the barbell hip thrust or its effects on gluteus maximus EMG activity, strength, sprint running speed, or gluteal development, nor has it been compared to the back squat.

The purpose of this investigation was to compare lower body muscle activity between the back squat and barbell hip thrust. Since previous investigations have revealed that the gluteus maximus has at least three functional subdivisions proximally to distally and the upper and lower portions of the gluteus maximus have been shown to activate uniquely during stair ambulation and prone hip extension at varying levels of hip abduction,[21-23] muscle activity was recorded for both the upper and lower gluteus maximus. Firstly, due to the findings of Worrell and colleagues[24] showing that gluteus maximus EMG is greater during MVICs in full hip extension compared to hip flexion, it was hypothesized that the barbell hip thrust would elicit greater upper and lower gluteus maximus EMG activity compared to the back squat in both dynamic and isometric conditions. Secondly, on the basis of previous studies showing that the back squat elicits high levels of quadriceps EMG activity but low levels of hamstrings EMG activity,[25] it was hypothesized that the back squat would elicit greater vastus lateralis EMG activity and less biceps femoris EMG activity compared to the barbell hip thrust in both dynamic and isometric conditions.

METHODS

Subjects

Thirteen healthy women (age = 28.9 ± 5.11 years; height = 164 ± 6.26 cm; body mass = 58.2 ± 6.37 kg) participated in this study. Subjects had 7.00 ± 5.80 years of resistance training experience and had a 10RM of 53.2 ± 17.0 kg and 87.4 ± 19.3 kg on the back squat and barbell hip thrust, respectively. Inclusion criteria required subjects to be between 20 to 40 years of age, have at least 3 years of consistent resistance training experience, and be familiar with performance of both the back squat and barbell hip thrust exercises. All subjects were healthy and free of any musculoskeletal or neuromuscular injuries, pain, or illnesses. Subjects filled out an Informed Consent and Physical Activity Readiness Questionnaire (PAR-Q). Any subject that answered "Yes" to any of the questions on the PAR-Q was excluded. Subjects were advised to refrain from training their lower body for 72 hours prior to testing. To ensure acceptable performance in the back squat and barbell hip thrust, subjects performed each movement using only a barbell while the lead researcher evaluated technique. If a subject reported pain, discomfort, or failed to perform the movement correctly, she was excluded from participation. If, for any reason, a subject could not complete a trial, her data was discarded. The study was approved by the Auckland University of Technology Ethics Committee.

Procedures

Subjects first performed a 10-minute general warm-up consisting of various dynamic stretches for the lower body musculature. Afterwards, three progressively heavier specific warm-up sets were performed for both the back squat and barbell hip thrust exercises. Next, each subject performed as many repetitions as she could with a moderately heavy load that could not be performed for more than 10 repetitions. Subjects' 1RM's were then estimated by utilizing table 15.7 on page 394 by Baechle and colleagues[26]. Finally, subjects' 10RM's were estimated using the aforementioned table, which corresponded to 75% of the subjects' 1RM. This estimational approach is similar to that used by Vigotsky and colleagues[27]. Order of the testing was randomized.

Subjects were asked to wear appropriate clothing for access to the EMG electrode placement sites. Before placing the electrodes on the skin, excess hair was removed with a razor, and skin was cleaned and abraded using an alcohol swab. After preparation, self-adhesive disposable silver/silver chloride pre-gelled dual snap surface bipolar electrodes (Noraxon Product #272, Noraxon USA Inc, Scottsdale, AZ) with a diameter of 1 centimeter (cm) and an inter-electrode distance of 2 cm were attached in parallel to the fibers of the right upper gluteus maximus, lower gluteus maximus, biceps femoris, and vastus lateralis in concordance with the recommendations of Lyons and colleagues[22], Hermens and colleagues[28], and Fujisawa and colleagues[23]. In particular, the upper gluteus maximus electrodes were placed superior and lateral to a line drawn between the PSIS and the posterior greater trochanter, and the lower gluteus maximus electrodes were placed Inferior and medial to a line drawn between the PSIS and the posterior greater trochanter. After the electrodes were secured, a quality check was performed to ensure EMG signal validity.

Ten minutes after 10RM testing, maximum voluntary isometric contraction (MVIC) testing was performed. For the gluteus maximus, two MVIC positions were tested. The first involved a prone bent-leg hip extension against manual resistance applied to the distal thigh, as utilized by Boren and colleagues[29], and the second involved a standing glute squeeze. Pilot data from our lab revealed that a minority of subjects achieved higher levels of gluteus maximus EMG activity with the standing glute squeeze than during the prone bent-leg hip extension against manual resistance; thus, both conditions were recorded and EMG was normalized to whichever contraction elicited greater EMG activity. Biceps femoris MVIC was determined by having the subject lay prone and produce maximum knee flexion torque at 45º knee flexion against manual resistance applied to the distal leg just above the ankle, as reported by Mohamed and colleagues[30]. Two vastus lateralis MVIC positions were used. The first had the subject sit and produce maximum knee extension torque against manual resistance applied to the distal leg just above the ankle at 90º hip flexion and 90º knee flexion, as detailed by Kong and Van Haselen[31], while the second used a 90º hip flexion and 180º knee position. Whichever contraction elicited greater EMG activity was used for normalization. In all MVIC positions, subjects were instructed to contract the tested muscle "as hard as possible."

After ten minutes of rest following MVIC testing, subjects performed 10 repetitions utilizing their estimated 10RM of the back squat and the barbell hip thrust in a randomized order and counterbalanced fashion. During the back squat, subjects' feet were slightly wider than shoulder width apart, with toes pointed forward or slightly outward. Subjects descended until the tops of the thigh were parallel with the floor (*Figure 1*).[32] In accordance with Contreras and colleagues[20], the barbell hip thrust was performed by having subjects' upper backs on a bench, approximately 16 inches high. Subjects' feet were slightly wider than shoulder width apart, with toes pointed forward or slightly outward. The barbell was padded with a thick bar pad and placed over the subjects' hips. The subjects were instructed to thrust the bar upwards while maintaining a neutral spine and pelvis (*Figure 2*). Subjects were given 5 minutes of rest between sets. No pre-determined tempo was set as to better mimic typical training conditions.

Following 10 minutes of rest, subjects then performed 3-second isoholds for the back squat and barbell hip thrust exercises using the same estimated 10RM loads as they did during the dynamic tests. Order was randomized in a counterbalanced fashion and depth was set at parallel (in hip flexion) for the back squat and at lockout (at full hip extension) for the barbell hip thrust. Subjects were given 5 minutes of rest between sets.

Raw EMG signals were collected at 2000 Hz by a Myotrace 400 EMG unit (Noraxon USA Inc, Scottsdale, AZ). Data was sent in real time to a computer via Bluetooth and recorded and analyzed by MyoResearch 3.6 Clinical Applications software (Noraxon USA, Inc., Scottsdale, AZ). Signals of all 10 repetitions for the dynamic sets and for all 3 seconds of the isoholds were first filtered using a 10-500 Hz bandpass filter, followed by full-wave rectification and smoothing using root mean square (RMS) with a 100 ms window. Finally, mean and peak data were normalized to a mean peak of a 1000 ms window from the MVIC trials.

Statistical Analysis

Paired samples *t*-tests were performed using SPSS (Version 22.0, IBM Corp., Airmonk, NY, USA). Alpha was set to 0.05 for significance, and a Holm-Bonferroni correction was used to correct for multiple pairwise comparisons for each muscle tested. Adjusted p-values were reported. Effect sizes (ES) were calculated by Cohen's *d* using the formula M_1-M_2/SD, where means (M) from each group (back squat and barbell hip thrust) were subtracted and divided by the pooled standard deviation (SD). ES were defined as small, medium, and large for 0.20, 0.50, and 0.80, respectively.[33] Confidence intervals (95% CI) for each ES were also calculated.

RESULTS

The barbell hip thrust elicited significantly greater mean (ES = 1.55; 95% CI = 0.63 – 2.37; $p < 0.004$) and peak (ES = 1.22; 95% CI = 0.35 – 2.02; $p = 0.004$) upper gluteus maximus, mean (ES = 1.64; 95% CI = 0.70 – 2.47; $p = 0.004$) and peak (ES = 1.18; 95% CI = 0.31 – 1.97; $p = 0.038$) lower gluteus maximus, and mean (ES = 1.58; 95% CI = 0.66 – 2.41; $p = 0.004$) and peak (ES = 1.63; 95% CI = 0.69 – 2.45; $p < 0.004$) biceps femoris EMG activity than the back squat. There were no significant differences in mean (ES = -0.15; 95% CI = -0.91 – 0.63; $p = 0.531$) and peak (ES = -0.17; 95% CI = -0.94 – 0.60; $p = 0.400$) vastus lateralis EMG activity between the back squat and barbell hip thrust exercises (*Table 1*).

The barbell hip thrust isohold elicited significantly greater mean (ES = 1.36; 95% CI = 0.47 – 2.17; $p = 0.004$) and peak (ES = 1.37; 95% CI = 0.47 – 2.17; $p = 0.004$) upper gluteus maximus, mean (ES = 2.61; 95% CI = 1.50 – 3.56; $p < 0.001$) and peak (ES = 2.44; 95% CI = 1.36 – 3.36; $p < 0.001$) lower gluteus maximus, and mean (ES = 1.66; 95% CI = 0.72 – 2.49; $p = 0.001$) and peak (ES = 1.63; 95% CI = 0.70 – 2.46; $p = 0.001$) biceps femoris EMG activity than the back squat isohold. There were no significant differences in mean (ES = -0.25; 95% CI = -1.01 – 0.53; $p = 0.230$) and peak (ES = -0.18; 95% CI = -0.94 – 0.60; $p = 0.389$) vastus lateralis EMG activity between the back squat and barbell hip thrust isoholds (*Table 1*).

DISCUSSION

Results partially confirm the research hypotheses in that the barbell hip thrust elicited significantly greater gluteus maximus (upper mean ES: 1.55; upper peak ES: 1.22; lower mean

ES: 1.64; lower peak ES: 1.18) and biceps femoris (mean ES: 1.58; peak ES: 1.63) EMG activity than the back squat. However, the back squat failed to elicit significantly greater vastus lateralis (mean ES: -0.15; peak ES: -0.17) EMG activity than the barbell hip thrust.

It was not surprising that the barbell hip thrust elicited significantly greater gluteus maximus EMG activity than the back squat, both when assessed dynamically and during isoholds. Worrell and colleagues[24] described the EMG-hip angle relationship of the gluteus maximus during MVICs. Their data showed that when creating maximal isometric hip extension torque in an isokinetic dynamometer at 90º, 60º, 30º, and 0º hip angles, gluteus maximus EMG activity is lowest with the hip in 90º of hip flexion and highest with the hip in 0º of hip extension (neutral). Furthermore, because the knee is flexed during the barbell hip thrust, it is presumed that the hamstrings are under active insufficiency, thus requiring greater muscular effort from the gluteus maximus in order to generate sufficient hip extension torque. Since muscular effort appears to be greatest during the barbell hip thrust when the hips are in full extension but greatest in the back squat when the hips are in flexion,[20,34,35] it is logical that gluteus maximus EMG activity is greater during the barbell hip thrust than during the back squat. These results are especially pertinent to our findings in that during the isometric barbell hip thrust, the hips are in full extension, allowing for exceptionally high levels of upper and lower gluteus maximus EMG activity (upper = 87.1; lower = 116%), but during the isometric back squat, the hips are in flexion, and therefore, not as much gluteus maximus EMG activity (upper = 10.1%; lower = 20.9%) can be elicited. Prior to data collection, we recorded extensive pilot data which showed that this gluteus maximus EMG-angle relationship is remarkably predictable in multiple isometric testing positions, including MVICs performed during squat, deadlift, lunge, hip thrust, reverse hyper, back extension, and quadruped hip extension exercise positions at varying hip angles along the hip flexion/extension axis, with and without applied manual resistance. It appears that the shorter the muscle length, the greater the potential levels of gluteus maximus EMG activity. As noted by Robertson and colleagues[36], gluteus maximus EMG activity reached a minimum at the bottom of the eccentric phase of the back squat, where the muscle length reaches its maximum, even though Caterisano and colleagues[37] noted greater gluteus maximus activity in full-depth squats than in parallel and partial squats. However, Caterisano and colleagues[37] did not utilize relative loading, which may explain why greater EMG activity was observed in the full-depth squat than the parallel and partial squats.[12] Data for the back squat isohold was in line with Schaub and Worrell[38]; however, there were two key differences between their study and the present study. First, the squat depth used by Schaub and Worrell[38] was more shallow, and second, participants performed an overcoming isohold which involved maximally pushing against an immovable crossbar, whereas the present utilized a yielding isohold where subjects held a 10RM load in place.

Similarly, it was not surprising that the barbell hip thrust (dynamic = 40.8%; isometric = 42.5%) elicited significantly greater biceps femoris EMG activity than the back squat (dynamic = 14.9%; isometric = 7.38%), both when assessed dynamically and during isoholds. Numerous studies have found that the back squat routinely displays low levels of hamstrings EMG activity, especially in comparison with measurements taken from the quadriceps,[39-42] although some of these studies did not normalize EMG measurements,[39,41] which makes direct comparison between muscles difficult. Exactly why the back squat leads to low levels of EMG activity in the hamstrings is not entirely clear. The position of the barbell load relative to the hip and knee joints along with individual anthropometry might impact hip and knee extensor activity. At the thigh-parallel position, assuming similar shin angles, individuals with relatively long femurs and short torsos will necessarily exhibit greater forward trunk lean in order to keep the barbell centered over the feet.[43] This increased trunk lean has been shown to increase hip extension torque and decrease knee extension torque requirements during the back squat exercise,[44] which might increase hip extensor and decrease knee extensor EMG activity. Alternatively, it may relate to the bi-articular nature of the hamstrings musculature. While the squat involves hip extension, for which the hamstrings are a prime mover, it also involves knee extension, for which the hamstrings are an antagonist. Yamashita[45] compared hamstrings EMG activity during isolated hip extension and isolated knee extension movements performed with 20% of the MVIC moment to hamstrings EMG activity with a combined hip and knee extension movement using the same hip and knee extension moments. Hamstrings EMG activity in combined hip and knee extension only reached 42% of the level in the isolated hip extension movement, despite the hip extension moment being identical in each case. It was concluded that hamstrings EMG activity was depressed when combined hip and knee extension are performed compared to during isolated hip extension. This may occur because the hamstrings changed length to a greater extent when performing isolated hip extension compared to when performing combined hip and knee extension. Kwon and Lee[46] noted that the maximum hip extension torque and hamstrings EMG decrease at knee flexion angles greater than 60º, indicating that hamstring activity is markedly reduced when the knee is significantly bent.

In contrast, the failure of the back squat to display greater vastus lateralis EMG activity in comparison with the barbell hip thrust was unexpected. The back squat is well known to elicit high levels of quadriceps EMG activity in comparison with other lower body exercises, including the leg press and leg extension[47] and the Smith machine squat.[48] Thus, the failure of our trial to discern any difference in vastus lateralis EMG activity between the barbell hip thrust and the back squat deserves further investigation, particularly as the risk of type I error during post-hoc testing was managed by the use of the Holm-Bonferroni correction[49] rather than the more conservative Bonferroni correction.[50,51] It may be that the different quadriceps muscles display different levels of EMG activity during the barbell hip thrust, with the vastus lateralis being unusually highly activated. Or, perhaps heavier loads than the estimated 10RMs used in this study would have lead to significant differences in vastus lateralis activation. Alternatively, the barbell hip thrust may require very high levels of quadriceps co-contraction in order to stabilize the knee joint.

Caution should be taken when interpreting the practical implications of this study. It is tempting to speculate that muscle activity can be used as a gauge to predict strength and hypertrophy gains. After all, two recent papers have linked muscle activation with hypertrophy,[52,53] and another with strength gains.[54] However, at this point in time no training studies have been conducted comparing the hypertrophic effects or transfer of training in the back squat and barbell hip thrust exercises. Future research needs to be conducted to 1) test the hypothesis that the barbell hip thrust exercise leads to greater gluteus maximus and hamstrings hypertrophy than the back squat exercise, 2) discern whether adaptations transfer to sports performance, particularly in relation to sprint running, 3) verify that male and female subjects activate their hip and thigh muscles similarly during the back squat and barbell hip thrust exercises, and 4) analyze the joint range of motion, heart rate, force, velocity, power, joint power, impulse, work, and torque angle curves between the back squat and barbell hip thrust exercises.

Comparing results between EMG studies can be problematic. At the very least, for comparative analysis, two studies would need to have the same electrode site placements, MVIC positions, data processing and amplitude presentation, exercise form, resistance load, tempo, and effort, and exercise range of motion. This is rarely the case with EMG studies examining resistance training exercises. In addition, gender, age, and training age might influence the comparability between EMG studies as well. *Table 2* shows the various back squat EMG studies that have normalized EMG to MVIC. When examining the table, it is apparent that there are broad differences in EMG results between the studies, but these discrepancies can be explained when considering the aforementioned variables. For example, the studies utilized different electrode site placements, MVIC positions, loads, and ranges of motion, and they presented the amplitude differently as well. An in-depth discussion of EMG variables is beyond the scope of this article. For a closer investigation of the muscle activation during the back squat exercise, the reader is directed to a recent review article by Clark and colleagues[12]. When considering the aforementioned variables, the findings of this study are in line with previous research (*Table 2*).

Limitations of this study should be considered in the interpretation of its findings. Firstly, surface EMG is sensitive to things like neighboring crosstalk, sliding of the skin over the muscle belly, and changes in muscle belly geometry. An estimated 10RM was utilized, which may differ from subjects’ actual 10RM, which may be the case as the methods described by Baechle and colleagues[26] have not been validated in the hip thrust or back squat. Moreover, if the subjects could have performed extra repetitions during testing above their estimated 10RMs, we did not have them do so. Therefore, exercise testing was not carried out to momentary muscular failure for each exercise. Finally, relatively light loads were used in this study. Fairly linear relationships between load and EMG activity have been observed in exercises such as the good morning[27] and back squat[55], however, no such relationship has been established with the barbell hip thrust exercise. Therefore, the results of this study only apply to loads of approximately 75% of 1RM, or around a 10RM.

The back squat has long been a staple in strength training programs and is one of the most well researched exercises in the literature. The barbell hip thrust is a newer exercise that lacks longitudinal research. Fitness professionals can confidently incorporate back squats into their programs with the knowledge that they will lead to hypertrophy and performance improvements. The findings of this study indicate that fitness professionals can also justify the inclusion of barbell hip thrusts into their programming for developing the hip extensor musculature due to the superior mean and peak gluteus maximus and biceps femoris activity compared to the back squat. In cases where back squats cannot safely be performed, perhaps due to injury, pain, mobility deficits, or hip dysfunction, the greater stability of the barbell hip thrust would seem to make it an excellent alternative for developing the lower body musculature. Additionally, evidence suggests that individuals seeking to maximize their gluteus maximus development should incorporate barbell hip thrusts into their regimen.

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References

1. Souza RB, Powers CM. Differences in hip kinematics, muscle strength, and muscle activation between subjects with and without patellofemoral pain. *J Orthop Sports Phys Ther.* 2009;39(1):12-19.

2. Rowe J, Shafer L, Kelley K, et al. Hip strength and knee pain in females. *N Am J Sports Phys Ther.* 2007;2(3):164-169.

3. Dorn TW, Schache AG, Pandy MG. Muscular strategy shift in human running: dependence of running speed on hip and ankle muscle performance. *J Exp Biol.* 2012;215(Pt 11):1944-1956.

4. Roundtable C. Speed Development. *NSCA J.* 1984;5(6):12-20.

5. Duehring MD, Feldmann CR, Ebben WP. Strength and conditioning practices of United States high school strength and conditioning coaches. *J Strength Cond Res.* 2009;23(8):2188-2203.

6. Ebben WP, Blackard DO. Strength and conditioning practices of National Football League strength and conditioning coaches. *J Strength Cond Res.* 2001;15(1):48-58.

7. Ebben WP, Carroll RM, Simenz CJ. Strength and conditioning practices of National Hockey League strength and conditioning coaches. *J Strength Cond Res.* 2004;18(4):889-897.

8. Ebben WP, Hintz MJ, Simenz CJ. Strength and conditioning practices of Major League Baseball strength and conditioning coaches. *J Strength Cond Res.* 2005;19(3):538-546.

9. Simenz CJ, Dugan CA, Ebben WP. Strength and conditioning practices of National Basketball Association strength and conditioning coaches. *J Strength Cond Res.* 2005;19(3):495-504.

10. Hubley CL, Wells RP. A work-energy approach to determine individual joint contributions to vertical jump performance. *Eur J Appl Physiol Occup Physiol.* 1983;50(2):247-254.

11. Schache AG, Blanch PD, Dorn TW, Brown NA, Rosemond D, Pandy MG. Effect of running speed on lower limb joint kinetics. *Med Sci Sports Exerc.* 2011;43(7):1260-1271.

12. Clark DR, Lambert MI, Hunter AM. Muscle activation in the loaded free barbell squat: a brief review. *J Strength Cond Res.* 2012;26(4):1169-1178.

13. Seitz LB, Reyes A, Tran TT, de Villarreal ES, Haff GG. Increases in Lower-Body Strength Transfer Positively to Sprint Performance: A Systematic Review with Meta-Analysis. *Sports Med.* 2014.

14. Cronin J, Ogden T, Lawton T. Does increasing maximal strength improve sprint running performance? *Strength Cond J.* 2007;29(3):86-95.

15. Jacobson BH, Conchola EG, Glass RG, Thompson BJ. Longitudinal morphological and performance profiles for American, NCAA Division I football players. *J Strength Cond Res.* 2013;27(9):2347-2354.

16. Bartlett JL, Sumner B, Ellis RG, Kram R. Activity and functions of the human gluteal muscles in walking, running, sprinting, and climbing. *Am J Phys Anthropol.* 2014;153(1):124-131.

17. Jonhagen S, Ericson MO, Nemeth G, Eriksson E. Amplitude and timing of electromyographic activity during sprinting. *Scand J Med Sci Sports.* 1996;6(1):15-21.

18. Kyrolainen H, Avela J, Komi PV. Changes in muscle activity with increasing running speed. *J Sports Sci.* 2005;23(10):1101-1109.

19. Schache AG, Kim HJ, Morgan DL, Pandy MG. Hamstring muscle forces prior to and immediately following an acute sprinting-related muscle strain injury. *Gait Posture.* 2010;32(1):136-140.

20. Contreras B, Cronin J, Schoenfeld B. Barbell hip thrust. *Strength Cond J.* 2011;33(5):58-61.

21. McAndrew D, Gorelick M, Brown J. Muscles within muscles: a mechanomyographic analysis of muscle segment contractile properties within human gluteus maximus. *J Musculoskelet Res.* 2006;10(01):23-35.

22. Lyons K, Perry J, Gronley JK, Barnes L, Antonelli D. Timing and relative intensity of hip extensor and abductor muscle action during level and stair ambulation. An EMG study. *Phys Ther.* 1983;63(10):1597-1605.

23. Fujisawa H, Suzuki H, Yamaguchi E, Yoshiki H, Wada Y, Watanabe A. Hip Muscle Activity during Isometric Contraction of Hip Abduction. *J Phys Ther Sci.* 2014;26(2):187-190.

24. Worrell TW, Karst G, Adamczyk D, et al. Influence of joint position on electromyographic and torque generation during maximal voluntary isometric contractions of the hamstrings and gluteus maximus muscles. *J Orthop Sports Phys Ther.* 2001;31(12):730-740.

25. Ebben WP, Feldmann CR, Dayne A, Mitsche D, Alexander P, Knetzger KJ. Muscle activation during lower body resistance training. *Int J Sports Med.* 2009;30(1):1-8.

26. Baechle TR, Earle RW, National Strength & Conditioning Association (U.S.). *Essentials of strength training and conditioning.* 3rd ed. Champaign, IL: Human Kinetics; 2008.

27. Vigotsky AD, Harper EN, Ryan DR, Contreras B. Effects of load on good morning kinematics and EMG activity. *PeerJ.* 2015;3:e708.

28. Hermens HJ, Freriks B, Merletti R, et al. European recommendations for surface electromyography. *Roessingh Research and Development, Enschede.* 1999.

29. Boren K, Conrey C, Le Coguic J, Paprocki L, Voight M, Robinson TK. Electromyographic analysis of gluteus medius and gluteus maximus during rehabilitation exercises. *Int J Sports Phys Ther.* 2011;6(3):206-223.

30. Mohamed O, Perry J, Hislop H. Relationship between wire EMG activity, muscle length, and torque of the hamstrings. *Clin Biomech (Bristol, Avon).* 2002;17(8):569-579.

31. Kong PW, Van Haselen J. Revisiting the influence of hip and knee angles on quadriceps excitation measured by surface electromyography: original research article. *Int SportMed J.* 2010;11(2):313-323.

32. Pierce K. Basic Back Squat. *Strength Cond J.* 1997;19(2):20-21.

33. Cohen J. *Statistical power analysis for the behavioral sciences.* Routledge Academic; 1988.

34. Bryanton MA, Kennedy MD, Carey JP, Chiu LZ. Effect of squat depth and barbell load on relative muscular effort in squatting. *J Strength Cond Res.* 2012;26(10):2820-2828.

35. Bloomquist K, Langberg H, Karlsen S, Madsgaard S, Boesen M, Raastad T. Effect of range of motion in heavy load squatting on muscle and tendon adaptations. *Eur J Appl Physiol.* 2013;113(8):2133-2142.

36. Robertson DG, Wilson JM, St Pierre TA. Lower extremity muscle functions during full squats. *J Appl Biomech.* 2008;24(4):333-339.

37. Caterisano A, Moss RF, Pellinger TK, et al. The effect of back squat depth on the EMG activity of 4 superficial hip and thigh muscles. *J Strength Cond Res.* 2002;16(3):428-432.

38. Schaub PA, Worrell TW. EMG activity of six muscles and VMO: VL ratio determination during a maximal squat exercise. *J Sport Rehabil.* 1995;4:195-202.

39. Paoli A, Marcolin G, Petrone N. The effect of stance width on the electromyographical activity of eight superficial thigh muscles during back squat with different bar loads. *J Strength Cond Res.* 2009;23(1):246-250.

40. Isear JA, Jr., Erickson JC, Worrell TW. EMG analysis of lower extremity muscle recruitment patterns during an unloaded squat. *Med Sci Sports Exerc.* 1997;29(4):532-539.

41. McCaw ST, Melrose DR. Stance width and bar load effects on leg muscle activity during the parallel squat. *Med Sci Sports Exerc.* 1999;31(3):428-436.

42. Escamilla RF, Fleisig GS, Zheng N, et al. Effects of technique variations on knee biomechanics during the squat and leg press. *Med Sci Sports Exerc.* 2001;33(9):1552-1566.

43. McKean M, Burkett BJ. Does Segment Length Influence the Hip, Knee and Ankle Coordination During the Squat Movement? *Journal of Fitness Research.* 2012;1(1):23-30.

44. Fry AC, Smith JC, Schilling BK. Effect of knee position on hip and knee torques during the barbell squat. *J Strength Cond Res.* 2003;17(4):629-633.

45. Yamashita N. EMG activities in mono- and bi-articular thigh muscles in combined hip and knee extension. *Eur J Appl Physiol Occup Physiol.* 1988;58(3):274-277.

46. Kwon YJ, Lee HO. How different knee flexion angles influence the hip extensor in the prone position. *J Phys Ther Sci.* 2013;25(10):1295-1297.

47. Wilk KE, Escamilla RF, Fleisig GS, Barrentine SW, Andrews JR, Boyd ML. A comparison of tibiofemoral joint forces and electromyographic activity during open and closed kinetic chain exercises. *Am J Sports Med.* 1996;24(4):518-527.

48. Schwanbeck S, Chilibeck PD, Binsted G. A comparison of free weight squat to Smith machine squat using electromyography. *J Strength Cond Res.* 2009;23(9):2588-2591.

49. Holm S. A simple sequentially rejective multiple test procedure. *Scand Stat Theory Appl.* 1979:65-70.

50. Armstrong RA. When to use the Bonferroni correction. *Ophthalmic Physiol Opt.* 2014;34(5):502-508.

51. McLaughlin MJ, Sainani KL. Bonferroni, Holm, and Hochberg corrections: fun names, serious changes to p values. *PM R.* 2014;6(6):544-546.

52. Wakahara T, Fukutani A, Kawakami Y, Yanai T. Nonuniform muscle hypertrophy: its relation to muscle activation in training session. *Med Sci Sports Exerc.* 2013;45(11):2158-2165.

53. Wakahara T, Miyamoto N, Sugisaki N, et al. Association between regional differences in muscle activation in one session of resistance exercise and in muscle hypertrophy after resistance training. *Eur J Appl Physiol.* 2012;112(4):1569-1576.

54. Calatayud J, Borreani S, Colado JC, Martin F, Tella V, Andersen LL. Bench press and push-up at comparable levels of muscle activity results in similar strength gains. *J Strength Cond Res.* 2014.

55. Aspe RR, Swinton PA. Electromyographic and Kinetic Comparison of the Back Squat and Overhead Squat. *J Strength Cond Res.* 2014.

56. Gullett JC, Tillman MD, Gutierrez GM, Chow JW. A biomechanical comparison of back and front squats in healthy trained individuals. *J Strength Cond Res.* 2009;23(1):284-292.

57. Escamilla RF, Fleisig GS, Zheng N, Barrentine SW, Wilk KE, Andrews JR. Biomechanics of the knee during closed kinetic chain and open kinetic chain exercises. *Med Sci Sports Exerc.* 1998;30(4):556-569.

58. Manabe Y, Shimada K, Ogata M. Effect of slow movement and stretch-shortening cycle on lower extremity muscle activity and joint moments during squat. *J Sports Med Phys Fitness.* 2007;47(1):1-12.

Figure 1. Start (left) and end (right) and isohold (right) position of the back squat.

Figure 2. Start (top) and end (bottom) and isohold (bottom) position of the barbell hip thrust.

Table 1. Mean (± SD) and peak EMG amplitudes (% MVIC) of the upper gluteus maximus, lower gluteus maximus, biceps femoris, and vastus lateralis during the barbell hip thrust and back squat.

		Upper Gluteus Maximus	**Lower Gluteus Maximus**	**Biceps Femoris**	**Vastus Lateralis**
Mean	**Back Squat**	29.35 ± 16.45	45.29 ± 23.54	14.92 ± 6.64	110.35 ± 47.24
	Barbell Hip Thrust	69.46 ± 32.64 *	86.75 ± 26.99 *	40.78 ± 22.13 *	99.47 ± 92.28
Peak	**Back Squat**	84.85 ± 42.91	129.60 ± 60.45	37.50 ± 18.39	243.92 ± 121.63
	Barbell Hip Thrust	171.75 ± 90.99 *	215.85 ± 83.76 *	86.87 ± 38.81 *	215.83 ± 193.89
Iso Mean	**Back Squat**	10.11 ± 7.96	20.85 ± 19.95	7.38 ± 4.28	133.72 ± 107.59
	Barbell Hip Thrust	87.08 ± 79.43 *	115.72 ± 47.40 *	42.5 ± 29.61 *	110.66 ± 78.27
Iso Peak	**Back Squat**	17.87 ± 16.96	34.30 ± 32.77	13.73 ± 9.99	201.28 ± 162.69
	Barbell Hip Thrust	128.22 ± 112.92 *	180.45 ± 78.16 *	67.67 ± 45.77 *	175.82 ± 124.34

* Denotes a statistically significant difference from the back squat.

Statistically significantly greater EMG activity was observed in the barbell hip thrust for mean, peak, iso mean, and iso peak upper gluteus maximus, lower gluteus maximus, and biceps femoris when compared to the back squat.

Table 2. EMG findings of previous research on the back squat for the gluteus maximus, biceps femoris, and vastus lateralis muscles compared to current findings.

	Load	**Gluteus Maximus EMG**	**Biceps Femoris EMG**	**Vastus Lateralis EMG**
Gullett and colleagues[56]	70% of 1RM	n/a	~20% mean	~65% mean
Wilk and colleagues[47]	12RM	n/a	36% mean	54% peak
Escamilla and colleagues[57]	12RM	n/a	~ 90% peak	~ 80% peak
Manabe and colleagues[58]	30% of 1RM	~ 80% peak	~ 40% peak	~ 60% peak
Escamilla and colleagues[42]	12RM	n/a	41% peak	57% peak
Aspe & Swinton[55]*	75% of 1RM	~ 55% mean	~ 50% mean	~ 76% mean
Ebben and colleagues[25]	6RM	n/a	32% mean	91% mean
Contreras et al.	10RM	45% mean 130% peak **	15% mean 38% peak	110% mean 244% peak

* Utilized integrated EMG, average of the eccentric and concentric phases is presented

** Represents lower gluteus maximus data, as it was assumed that it might better represented how the middle gluteus maximus fibers would activate when compared to the upper gluteus maximus fibers.