A Comparison of Gluteus Maximus, Biceps Femoris, and Vastus Lateralis EMG Amplitude in the Parallel, Full, and Front Squat Variations in Resistance Trained Females

Article *in* Journal of applied biomechanics · August 2015

Impact Factor: 0.98 · DOI: 10.1123/jab.2015-0113 · Source: PubMed


Bret Contreras

42 PUBLICATIONS **119** CITATIONS

SEE PROFILE


Andrew Vigotsky

Northwestern University

17 PUBLICATIONS **6** CITATIONS

SEE PROFILE


Brad J Schoenfeld

City University of New York City - Lehman Col…

82 PUBLICATIONS **633** CITATIONS

SEE PROFILE


John Cronin

Auckland University of Technology

280 PUBLICATIONS **5,022** CITATIONS

SEE PROFILE

“A Comparison of Gluteus Maximus, Biceps Femoris, and Vastus Lateralis EMG Amplitude in the Parallel, Full, and Front Squat Variations in Resistance Trained Females” by Contreras B et al.
Journal of Applied Biomechanics
© 2015 Human Kinetics, Inc.

Section: Original Research

Article Title: A Comparison of Gluteus Maximus, Biceps Femoris, and Vastus Lateralis EMG Amplitude in the Parallel, Full, and Front Squat Variations in Resistance Trained Females

Authors: Bret Contreras[1], Andrew D. Vigotsky[2] , Brad J. Schoenfeld , Chris Beardsley[4] , and John Cronin[1, 5]

Affiliations: [1]Sport Performance Research Institute, Auckland University of Technology, Auckland, New Zealand. [2]Kinesiology Program, Arizona State University, Phoenix, AZ. [3]Department of Health Sciences, CUNY Lehman College, Bronx, NY. [4]Strength and Conditioning Research Limited, London, UK. [5]School of Exercise, Biomedical and Health Science, Edith Cowan University, Perth, Australia.

Journal: *Journal of Applied Biomechanics*

Acceptance Date: July 30, 2015

DOI: http://dx.doi.org/10.1123/jab.2015-0113

"A Comparison of Gluteus Maximus, Biceps Femoris, and Vastus Lateralis EMG Amplitude in the Parallel, Full, and Front Squat Variations in Resistance Trained Females" by Contreras B et al.
Journal of Applied Biomechanics

A comparison of gluteus maximus, biceps femoris, and vastus lateralis EMG amplitude in the parallel, full, and front squat variations in resistance trained females

Bret Contreras, MA [1], Andrew D. Vigotsky [2], Brad J. Schoenfeld, PhD [3], Chris Beardsley [4], John Cronin, PhD [1, 5]

[1] Sport Performance Research Institute, Auckland University of Technology, Auckland, New Zealand

[2] Kinesiology Program, Arizona State University, Phoenix, AZ, USA

[3] Department of Health Sciences, CUNY Lehman College, Bronx, NY, USA

[4] Strength and Conditioning Research Limited, London, UK

[5] School of Exercise, Biomedical and Health Science, Edith Cowan University, Perth, Australia

Funding: No funding was obtained for this study.

Conflict of Interest Disclosure: The authors report no conflicts of interest.

Correspondence Address: avigotsk@asu.edu

Running head: Squat EMG

Abstract

Front, full, and parallel squats are some of the most popular squat variations. The purpose of this investigation was to compare mean and peak electromyography (EMG) amplitude of the upper gluteus maximus, lower gluteus maximus, biceps femoris, and vastus lateralis of front, full, and parallel squats. Thirteen healthy women (age = 28.9 ± 5.1 years; height = 164 ± 6.3 cm; body mass = 58.2 ± 6.4 kg) performed ten repetitions of their estimated 10-repetition maximum of each respective variation. There were no significant ($p \leq 0.05$) differences between full, front and parallel squats in any of the tested muscles. Given these findings, it can be concluded that the front, full, or parallel squat can be performed for similar levels of EMG activity. However, given the results of previous research, it is recommended that individuals utilize a full range of motion when squatting, assuming full range can be safely achieved, in order to promote more favorable training adaptations. Furthermore, despite requiring lower loads, the front squat may provide a similar training stimulus to the back squat.

Keywords: relative loading, electromyography, lower extremity, resistance training, exercise

Word Count: 3,577

Introduction

The squat is not only a core movement in Olympic weightlifting and powerlifting; it is also a staple exercise for athletes and bodybuilders. Due to its applicability to functional exercise and sport, numerous variations have been developed and employed in the fields of strength and conditioning and physical therapy. Many of these squat variations have been investigated and/or compared in terms of kinetics,[1-4] kinematics,[1,3,5,6] muscle activation,[1,2,7,8] hormonal response,[9-11] postactivation potentiation,[12-15] correlations to performance,[16-19] and transfer of training.[20-23] In addition, several reviews[24-27] and one meta-analysis[28] have been conducted on the squat exercise.

Like most exercise and sports medicine research, a disproportionate amount of previous research on the squat was completed on male subjects.[29] To the authors’ knowledge, only two studies have investigated squat electromyography (EMG) amplitude in female subjects,[30,31] one of which noted greater biceps femoris EMG in females than their male counterparts.[31] Furthermore, anthropometric and kinematic differences exist between males and females during the squat, which means that squat data cannot be extrapolated between sexes.[32] Therefore, there is a need to fill this gender gap in the literature.

With regards to gluteus maximus EMG amplitude in the squat exercise, several important studies have been conducted. Caterisano and colleagues[33] investigated the effects of squat depth on gluteus maximus EMG. The investigators found that gluteus maximus EMG amplitude significantly increased with depth (35.5 vs. 28.0%). However, as noted by Clark and colleagues,[34] Caterisano and colleagues[33] did not utilize the same relative loading at each squat depth tested, which may have affected the outcome. Paoli and colleagues[35] and McCaw & Melrose[36] both found significant increases (.0288 vs. .0205 mV and 9.4 vs. 8.3 µV.s, respectively) in gluteus maximus EMG amplitude and integrated EMG values, respectively, with increases in squat stance width. Aspe & Swinton[37] analyzed the back squat and the overhead squat and found that, at 90% 3-repetition maximum (RM), the back squat elicited significantly greater gluteus maximus EMG amplitude than the overhead squat (92.7 vs. 60.9%), in addition to significantly greater biceps femoris (71.1 vs. 54.0%) and vastus lateralis (vastus lateralis) (99.2 vs. 82.3%) amplitude.

A number of studies have compared front and back squat variations.[1,8,23,38-43] Gullett and colleagues[1] examined kinetic and EMG differences between the front and back squats and found that the back squat exhibited significantly greater knee moments (1.0 vs. 0.7 N.m/kg), but no significant differences between biceps femoris, rectus femoris, semitendinosus, vastus lateralis, vastus medialis, or erector spinae EMG amplitude were found. Intuitively, the back squat utilizes greater energy from the hips while the front squat utilizes greater energy from the knees.[41] Russell & Phillips[39] found similar knee extensor moments, trunk extensor moments, trunk angles, and lumbar compressive and shear forces between front and back squats. Stuart and colleagues[38] described similar anteroposterior shear and compressive forces at the knee, knee flexion/extension moments, and quadriceps EMG amplitude in front and back squats. In this study, hamstring EMG amplitude was found to differ significantly between the front and back squat at 90 degrees and 60 degrees in the ascent phase, but the authors failed to specify which exercise variation elicited greater hamstring activity. Lastly, Yavuz and colleagues[43] investigated the EMG activity of the vastus lateralis, vastus medialis, rectus femoris, semitendinosus, biceps femoris, gluteus maximus, and erector spinae in front and back squats performed to 90° knee flexion. The only differences the investigators observed were greater vastus medialis EMG activity in the front squat, and greater semitendinosus EMG activity during the ascending phase of the back squat.

Numerous studies have compared differences in squat depths.[5,6,30,33,44-47] Gorsuch and colleagues[30] found that parallel squats elicited significantly greater rectus femoris (0.18 vs. 0.14 mV) and erector spinae (0.16 vs. 0.13 mV) EMG amplitude than partial squats but reported that hamstring EMG amplitude was not statistically different. Bryanton and colleagues[5] described an increase in knee extensor and hip extensor relative muscular effort with increases in squat depth. Both patellofemoral joint reaction forces and external knee flexion moments increase with increases in squat depth.[46,47] Drinkwater and colleagues[44] found that partial squats produced greater peak power and peak forces, but full squats produced greater peak velocities and work. Esformes and Bampouras[45] found that in a study examining the effects of postactivation potentiation, parallel squats led to significantly greater improvements than quarter squats in countermovement jump height, peak power, impulse, and flight time (22.2–28.0%). Wretenberg and colleagues[6] described greater knee moments and greater biceps femoris EMG amplitude during deep squats in comparison to parallel squats, but the two squat styles exhibited similar hip moments, rectus femoris EMG amplitude, and vastus lateralis EMG amplitude.

The front, full, and parallel squat are three common variations of the squat. The purpose of this investigation was to compare upper gluteus maximus, lower gluteus maximus, biceps femoris, and vastus lateralis EMG amplitude during 10 repetitions utilizing estimated 10RM front, full, and parallel squat loads in resistance trained women. Previous researchers have indicated that hamstrings EMG amplitude is likely to be unaffected by depth, quadriceps EMG amplitude is likely to be increased by increasing depth, and that the effect of depth on gluteus maximus EMG amplitude is unclear. Therefore, it is hypothesized that there would be no difference in upper gluteus maximus, lower gluteus maximus, or biceps femoris EMG amplitude between the front, full, and parallel squat, but the front and full squat would elicit greater vastus lateralis EMG amplitude than the parallel squat.

Methods

Thirteen experienced, resistance trained women (age = 28.9 ± 5.1 years; height = 164 ± 6.3 cm; body mass = 58.2 ± 6.4 kg) participated in this study. Subjects had 7.00 ± 5.8 years of resistance training experience and a 10RM of 39.2, 46.7, and 53.1 kg in the front, full and parallel squat, 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 the front, full, and parallel squat. 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 or refused to sign the Informed Consent would have been excluded. Subjects were advised to refrain from training their lower body for 72 hours prior to testing. To ensure acceptable performance in the three squat variations, 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 would have been excluded from participation. If, for any reason, a subject could not complete a trial, her data would have been discarded. All recruited subjects fulfilled the inclusion criteria, and no subjects were excluded. The study was approved by the Auckland University of Technology Ethics Committee.

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 the front, full, and parallel squat. Next, subjects' 10RM in each squat variation were calculated using the methods described by Baechle and colleagues[48] and Vigotsky and colleagues[49] by performing as many repetitions with what each subject perceived to be a moderately heavy load. 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 Hermens and colleagues[50] and Fujisawa and colleauges.[51] More specifically, "[upper gluteus maximus] electrodes were placed two finger's width above the line just under the spina iliaca posterior superior and the trochanter major; [lower gluteus maximus] electrodes were set below the same line,"[51] biceps femoris electrodes were "placed at 50% on the line between the ischial tuberosity and the lateral epicondyle of the tibia,"[50] and vastus lateralis electrodes were "placed at 2/3 on the line from the anterior spina iliaca superior to the lateral side of the patella."[50] After the electrodes were secured, a quality check was performed to ensure EMG signal validity.

Ten minutes after estimated 10RM testing, maximum voluntary isometric contraction (MVIC) testing was performed. For the gluteus maximus, 2 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,[52] and the second involved a standing glute squeeze. Pilot data from our lab revealed that some subjects achieve higher levels of gluteus maximus EMG amplitude 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 amplitude. 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.[53] 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 & Van Haselen[54] (except without the use of an isokinetic dynamometer), while the second used a 90º hip flexion and 180º knee position. Whichever contraction elicited greater EMG amplitude 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 front, full, and parallel squats in a randomized order and counterbalanced fashion. During all squat variations, subjects' feet were slightly wider than shoulder width apart, with toes pointed forward or slightly outward. For the front squat, the barbell was placed across the anterior deltoids and clavicles. Subjects fully flexed their elbows to position the upper arms parallel to the floor (Figure 1).[1] During both back squat variations (full and parallel), the barbell was placed in the high bar position across the shoulders on the trapezius, slightly above the posterior aspect of the deltoids (Figure 2, Figure 3).[1] In both the front and full squat, subjects descended until the knees were maximally flexed (Figure 1, Figure 2).[55] Descent during the parallel squat was limited to the point at which the tops of the thighs were parallel with the floor (Figure 3).[56] Subjects were given 5 minutes of rest between sets. No pre-determined tempo was set as to better mimic typical training conditions.

Raw EMG signals were collected at 2000 Hz, with a gain of 500, 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). A 10-500 Hz bandpass filter was applied to EMG data. Signals of all 10 repetitions were rectified and smoothed with a root mean square (RMS) algorithm with a 100 ms window. Mean and peak data were normalized to a mean peak of a 1000 ms window from the MVIC trials. While peak allows for all near-instantaneous increases in muscle activation to be seen, mean is robust to both movement artifact and time, thus providing a reliable average of EMG amplitude over the entire movement.[57]

Repeated measures analyses of variance (ANOVA) were performed using Stata 13 (StataCorp LP, College Town, TX), wherein mean and peak EMG between exercises, within subjects, and within muscle effects were calculated. Bonferroni *post hoc* tests were performed on any measure that achieved a main effect. Alpha was set to 0.05 for significance. Partial η^2 effect sizes were calculated and reported, as were their 95% confidence intervals (95% CI). Partial η^2 effect sizes were interpreted based upon the guidelines of Cohen [58]; that is, a partial η^2 of 0.02 is small, 0.13 is medium, and 0.26 is large.

RESULTS

No differences were found between any measured outcomes, except for vastus lateralis peak EMG, which revealed no pairwise differences.

No main effects were found for mean EMG amplitude of the upper gluteus maximus ($p = 0.98$; $F_{2,24} = 0.02$; partial $\eta^2 = 0.00$; 95% CI = 0.0 – 1.0), lower gluteus maximus ($p = 0.474$; $F_{2,24}$

= 0.77; partial η^2 = 0.06; 95% CI = 0.0 – 0.24), biceps femoris (p = 0.31; $F_{2,24}$ = 1.23; partial η^2 = 0.09; 95% CI = 0.0 – 0.29), and vastus lateralis (p = 0.21; $F_{2,24}$ = 1.69; partial η^2 = 0.12; 95% CI = 0.0 – 0.33) (Table 1). The partial η^2 values suggest small effects were observed for the upper gluteus maximus, lower gluteus maximus, and biceps femoris, and a medium effect for the vastus lateralis; however, it cannot be said that these effects were not due to chance alone.

No main effects were found for peak EMG amplitude for the upper gluteus maximus (p = 0.90; $F_{2,24}$ = 0.10; partial η^2 = 0.01; 95% CI = 0.0 – 0.10), lower gluteus maximus (p = 0.60; $F_{2,24}$ = 0.52; partial η^2 = 0.04; 95% CI = 0.0 – 0.21), or biceps femoris (p = 0.96; $F_{2,24}$ = 0.04; partial η^2 = 0.00; 95% CI = 0.0 – 0.04). Although a main effect was found for peak vastus lateralis EMG activity (p = 0.03; $F_{2,24}$ = 4.27; partial η^2 = 0.26; 95% CI = 0.0 – 0.47), Bonferroni *post hoc* testing revealed no pairwise effects (Table 1). The partial η^2 values suggest small effects were observed for the lower gluteus maximus and biceps femoris, and a large effect for the vastus lateralis; however, for the lower gluteus maximus and biceps femoris, it cannot be said that these effects were not due to chance alone.

Discussion

Our hypothesis was partially confirmed in that there were no observable differences between full, front, and parallel squats in the UGM, LGM, and biceps femoris; however, the front and full squat failed to elicit significantly greater vastus lateralis EMG amplitude than the parallel squat. Unsurprisingly, subjects utilized the greatest amount of load in the parallel squat (53.1 ± 17.0 kg), followed by full (46.7 ± 17.1 kg) and front (39.2 ± 15.6 kg) squats, respectively. These findings are in line with Gullett and colleagues,[1] Gorsuch and colleagues,[30] and Yavuz and colleagues,[43] where investigators found no significant differences between mean EMG amplitude of the muscles measured in this study. Specifically, Gullet and colleagues[1] found no differences in vastus lateralis or biceps femoris EMG during front and parallel squats, Gorsuch and colleagues[30] did not find significant differences in biceps femoris EMG during partial and parallel squats, and Yavuz and colleagues did not find differences in gluteus maximus, biceps femoris, or vastus lateralis EMG during front and back squats. However, Gullett and colleagues[1] also investigated the rectus femoris, vastus medialis, semitendinosus, and erector spinae, Gorsuch and Colleagues[30] also investigated the rectus femoris, erector spinae, and gastrocnemius, and Yavuz and colleagues[43] also investigated the vastus medialis, rectus femoris, semitendinosus, and erector spinae; thus, it is possible that had this study investigated these muscles, too, differences may have been observed. It should be noted that our results differ from Caterisano and colleagues,[33] who found that gluteus maximus EMG amplitude significantly increased with depth. However, as noted by Clark and colleagues,[34] Caterisano and colleagues[33] did not utilize relative loading, which seems to have affected the outcome, as in this study, subjects used 12.8% greater 10RM loads during the parallel squat compared to the full squat.

Although no significant pairwise differences were observed between any measured outcomes, peak vastus lateralis EMG activity during front squats was about 21.5% greater than during parallel squats, despite lighter 10RM loads. This large difference in EMG amplitude, combined with the large effect size, occurring without a significant effect suggests that our study may have been underpowered. Additionally, visual inspection of the results reveals a non-significant trend for increasing peak vastus lateralis EMG amplitude from the parallel squat to the full squat to the front squat, and for increasing mean vastus lateralis EMG amplitude from the parallel squat to the full and front squat, in which a medium effect size was observed (Table 1). These findings seem to be coherent with those of Bryanton and colleagues,[5] who reported that the net knee extension moment increased to a greater extent with increasing squat depth than with increasing squat load. The findings may also relate to the more favorable training adaptations observed by Bloomquist and colleagues,[21] where investigators found that squats using a greater range of motion led to greater quadriceps hypertrophy. It is unfortunate that Bloomquist and colleagues[21] did not measure gluteus maximus hypertrophy, nor has it been measured in any other barbell squat study, to the authors' knowledge.

As expected, biceps femoris was not highly activated during any of the squat variations. This is in concordance with other studies,[1,6,37] including Ebben and colleagues,[59] which concluded that squatting was insufficient for hamstring development. On the basis of these findings, it seems logical that other exercises, such as leg curls and stiff-leg deadlifts, should be implemented to ensure maximal hamstring development.

Maximum hip and knee moments in the squat occur in considerable hip and knee flexion.[3,6,46] Because the greatest EMG amplitude is elicited from the gluteus maximus in full hip extension,[60] and from the biceps femoris in full hip extension and 45º knee flexion,[53] this may explain why the squat does not maximally activate these muscles. Alternatively, the hamstrings might not be highly activated because increasing hamstrings reliance necessitates greater knee extensor moments to counter the hamstrings' knee flexion moment.[61] However, the MVIC position for the vastus lateralis is obtained with both the hip and knee flexed to 90º.[54] This is the knee angle at which, in the squat, there is a notable amount of net knee extension moment.[3] This may therefore explain the higher EMG values from the vastus lateralis than the gluteus maximus or biceps femoris. The seemingly high vastus lateralis values in this investigation may also be due to the sample being female subjects, whereas most previous studies utilized male subjects. Research has shown that women adopt more knee-dominant movement patterns, which would necessarily require more torque from and therefore more activation of the quadriceps.[31]

Alternatively, it could be due to decreased stability while performing the MVIC trial, as subjects were not strapped into a dynamometer – the subjects sat on a flat bench and the investigator held the leg stable while simultaneously generating manual resistance against the lower limb.

The front squat is performed with the torso more upright, while the back squat is performed with more forward lean.[40] Despite this difference, in males, hip extension torque has been found to be similar,[39] which may explain why there were no differences in gluteus maximus or biceps femoris EMG between front and back squats. However, further research must be completed in females to confirm this theorization. It should be noted that due to individual differences[62] and pathologies such as femoroacetabular impingement,[63] the deep squat may not be a viable option for all individuals. More specifically, Elson & Aspinall[62] described a large variability of hip flexion mobility between human subjects (80-140º), whereby after each subject reached his or her hip flexion limit, posterior pelvic tilt occurred.

A limitation of investigating the deep squat is the inability to standardize depth amongst subjects. Inter-individual variances in lower body mass, flexibility, and other factors ultimately determine how low a given subject can squat without compromising exercise technique. We did not measure the specific joint angles in the full squat but rather instructed subjects to descend as low as possible while maintaining proper form. Whether such differences has an impact on lower body muscle activation remains to be elucidated.

This was the first study to compare front, parallel, and full squats in women; however, generalizability is specific to young, resistance-trained women. Considering that highly trained women have been shown to possess greater hip mobility compared to men,[64] and that many men prefer the low bar squat position as opposed to the high bar squat position we used in this study, it is recommended that more research be performed to gain further insight as to how these squat variations in addition to low bar squat variations affect the EMG amplitude in other populations of women, in addition to populations of men.

The front squat appears to be a viable alternative to the back squat since muscle activation is similar between the two variations. Given that both long term training and acute biomechanical investigations favor deep squats over parallel or partial squats, it is recommended that an athlete squat as deeply as he or she can, provided he or she can do so safely. However, deep squats are not appropriate for everyone, as it is necessary to have the requisite hip and ankle mobility to safely and properly descend into a deep squat. Individuals with limited hip flexion ability, whether due to pathologic or morphologic variance, will not be able to squat as deeply while maintaining a lordotic curvature of the spine, which could lead to back injury over time.

References

1. Gullett JC, Tillman MD, Gutierrez GM, Chow JW. A biomechanical comparison of back and front squats in healthy trained individuals. *J Strength Cond Res.* 2008;23(1):284-292.

2. 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.

3. Escamilla RF, Fleisig GS, Lowry TM, Barrentine SW, Andrews JR. A three-dimensional biomechanical analysis of the squat during varying stance widths. *Med Sci Sports Exerc.* 2001;33(6):984-998.

4. 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.

5. 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.

6. Wretenberg P, Feng Y, Arborelius UP. High- and low-bar squatting techniques during weight-training. *Med Sci Sports Exerc.* 1996;28(2):218-224.

7. 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.

8. Comfort P, Pearson SJ, Mather D. An electromyographical comparison of trunk muscle activity during isometric trunk and dynamic strengthening exercises. *J Strength Cond Res.* 2011;25(1):149-154.

9. Jones MT, Ambegaonkar JP, Nindl BC, Smith JA, Headley SA. Effects of unilateral and bilateral lower-body heavy resistance exercise on muscle activity and testosterone responses. *J Strength Cond Res.* 2012;26(4):1094-1100.

10. Shaner AA, Vingren JL, Hatfield DL, Budnar RG, Jr., Duplanty AA, Hill DW. The acute hormonal response to free weight and machine weight resistance exercise. *J Strength Cond Res.* 2014;28(4):1032-1040.

11. Cook CJ, Crewther BT. Changes in salivary testosterone concentrations and subsequent voluntary squat performance following the presentation of short video clips. *Hormones and behavior.* 2012;61(1):17-22.

12. Witmer CA, Davis SE, Moir GL. The acute effects of back squats on vertical jump performance in men and women. *Journal of sports science & medicine.* 2010;9(2):206-213.

13. Moir GL, Mergy D, Witmer C, Davis SE. The acute effects of manipulating volume and load of back squats on countermovement vertical jump performance. *J Strength Cond Res.* 2011;25(6):1486-1491.

14. Hanson ED, Leigh S, Mynark RG. Acute effects of heavy- and light-load squat exercise on the kinetic measures of vertical jumping. *J Strength Cond Res.* 2007;21(4):1012-1017.

15. Weber KR, Brown LE, Coburn JW, Zinder SM. Acute effects of heavy-load squats on consecutive squat jump performance. *J Strength Cond Res.* 2008;22(3):726-730.

16. Chelly MS, Cherif N, Amar MB, et al. Relationships of peak leg power, 1 maximal repetition half back squat, and leg muscle volume to 5-m sprint performance of junior soccer players. *J Strength Cond Res.* 2010;24(1):266-271.

17. Cunningham DJ, West DJ, Owen NJ, et al. Strength and power predictors of sprinting performance in professional rugby players. *J Sports Med Phys Fitness.* 2013;53(2):105-111.

18. Wisloff U, Castagna C, Helgerud J, Jones R, Hoff J. Strong correlation of maximal squat strength with sprint performance and vertical jump height in elite soccer players. *Br J Sports Med.* 2004;38(3):285-288.

19. McBride JM, Blow D, Kirby TJ, Haines TL, Dayne AM, Triplett NT. Relationship between maximal squat strength and five, ten, and forty yard sprint times. *J Strength Cond Res.* 2009;23(6):1633-1636.

20. Morrissey MC, Harman EA, Frykman PN, Han KH. Early phase differential effects of slow and fast barbell squat training. *Am J Sports Med.* 1998;26(2):221-230.

21. 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.

22. Rhea MR, Kenn JG, Dermody BM. Alterations in speed of squat movement and the use of accommodated resistance among college athletes training for power. *J Strength Cond Res.* 2009;23(9):2645-2650.

23. Hartmann H, Wirth K, Klusemann M, Dalic J, Matuschek C, Schmidtbleicher D. Influence of squatting depth on jumping performance. *J Strength Cond Res.* 2012;26(12):3243-3261.

24. Hartmann H, Wirth K, Klusemann M. Analysis of the load on the knee joint and vertebral column with changes in squatting depth and weight load. *Sports Med.* 2013;43(10):993-1008.

25. Schoenfeld BJ. Squatting kinematics and kinetics and their application to exercise performance. *J Strength Cond Res.* 2010;24(12):3497-3506.

26. 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.

27. Escamilla RF. Knee biomechanics of the dynamic squat exercise. *Med Sci Sports Exerc.* 2001;33(1):127-141.

28. 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.

29. Costello JT, Bieuzen F, Bleakley CM. Where are all the female participants in Sports and Exercise Medicine research? *Eur J Sport Sci.* 2014;14(8):847-851.

30. Gorsuch J, Long J, Miller K, et al. The effect of squat depth on multiarticular muscle activation in collegiate cross-country runners. *J Strength Cond Res.* 2013;27(9):2619-2625.

31. Lynn SK, Noffal GJ. Lower extremity biomechanics during a regular and counterbalanced squat. *J Strength Cond Res.* 2012;26(9):2417-2425.

32. 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.

33. 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.

34. 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.

35. 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.* 2008;23(1):246-250.

36. 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.

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

38. Stuart MJ, Meglan DA, Lutz GE, Growney ES, An KN. Comparison of intersegmental tibiofemoral joint forces and muscle activity during various closed kinetic chain exercises. *Am J Sports Med.* 1996;24(6):792-799.

39. Russell PJ, Phillips SJ. A preliminary comparison of front and back squat exercises. *Research quarterly for exercise and sport.* 1989;60(3):201-208.

40. Diggin D, O'Regan C, Whelan N, et al. A biomechanical analysis of front versus back squat: injury implications. Paper presented at: ISBS-Conference Proceedings Archive2011.

41. Braidot A, Brusa M, Lestussi F, Parera G. Biomechanics of front and back squat exercises. Paper presented at: Journal of Physics: Conference Series2007.

42. Yetter M, Moir GL. The acute effects of heavy back and front squats on speed during forty-meter sprint trials. *J Strength Cond Res.* 2008;22(1):159-165.

43. Yavuz HU, Erdag D, Amca AM, Aritan S. Kinematic and EMG activities during front and back squat variations in maximum loads. *J Sports Sci.* 2015;33(10):1058-1066.

44. Drinkwater EJ, Lawton TW, Lindsell RP, Pyne DB, Hunt PH, McKenna MJ. Training leading to repetition failure enhances bench press strength gains in elite junior athletes. *J Strength Cond Res.* 2005;19(2):382-388.

45. Esformes JI, Bampouras TM. Effect of back squat depth on lower-body postactivation potentiation. *J Strength Cond Res.* 2013;27(11):2997-3000.

46. Cotter JA, Chaudhari AM, Jamison ST, Devor ST. Knee joint kinetics in relation to commonly prescribed squat loads and depths. *J Strength Cond Res.* 2013;27(7):1765-1774.

47. Cotter JA, Chaudhari AM, Jamison ST, Devor ST. Differences in Rate of Increased Patellofemoral Joint Reaction Force in the Back Squat Exercise. *Med Sci Sports Exerc.* 2010;42(5):681.

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

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

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

51. 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.

52. 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.

53. 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.

54. 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.

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

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

57. Renshaw D, Bice MR, Cassidy C, Eldridge JA, Powell, Douglas W. A Comparison of Three Computer-based Methods Used to Determine EMG Signal Amplitude. *International Journal of Exercise Science.* 2010;3(1):1-7.

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

59. Ebben WP, Leigh DH, Jensen RL. The role of the back squat as a hamstring training stimulus. *Strength Cond J.* 2000;22(5):15.

60. 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.

61. Bryanton MA, Carey JP, Kennedy MD, Chiu LZ. Quadriceps effort during squat exercise depends on hip extensor muscle strategy. *Sports biomechanics / International Society of Biomechanics in Sports.* 2015;14(1):122-138.

62. Elson R, Aspinall G. Measurement of hip range of flexion-extension and straight-leg raising. *Clinical orthopaedics and related research.* 2008;466(2):281-286.

63. Lamontagne M, Kennedy MJ, Beaule PE. The effect of cam FAI on hip and pelvic motion during maximum squat. *Clin Orthop Relat Res.* 2009;467(3):645-650.

64. Drezewska M, Galuszka R, Sliwinski Z. Hip joint mobility in dancers: preliminary report. *Ortop Traumatol Rehabil.* 2012;14(5):443-452.

Figure 1. Front squat form.

Figure 2. Full squat form.

Figure 3. Parallel squat form.

“A Comparison of Gluteus Maximus, Biceps Femoris, and Vastus Lateralis EMG Amplitude in the Parallel, Full, and Front Squat Variations in Resistance Trained Females” by Contreras B et al.
Journal of Applied Biomechanics

Table 1. Mean ± SD of EMG (%MVIC) values in the parallel, full, and front squat.

		Parallel	**Full**	**Front**
Mean	**Upper gluteus maximus**	29.35 ± 16.45	29.58 ± 16.26	29.15 ± 14.35
	Lower gluteus maximus	45.29 ± 23.54	42.24 ± 21.51	43.89 ± 20.75
	Biceps femoris	14.92 ± 6.64	14.39 ± 6.41	13.11 ± 4.70
	Vastus lateralis	110.35 ± 47.24	123.82 ± 67.42	124.22 ± 72.96
Peak	**Upper gluteus maximus**	84.85 ± 42.91	88.13 ± 47.83	84.62 ± 50.48
	Lower gluteus maximus	129.60 ± 60.45	124.76 ± 55.44	134.62 ± 55.71
	Biceps femoris	37.50 ± 18.39	38.59 ± 16.82	39.35 ± 22.79
	Vastus lateralis	243.92 ± 121.63	280.54 ± 166.16	302.61 ± 191.80