Journal of Strength and Conditioning Research, 2002, 16(3), 428–432

The Effect of Back Squat Depth on the EMG Activity of 4 Superficial Hip and Thigh Muscles

ANTHONY CATERISANO, RAYMOND F. MOSS, THOMAS K. PELLINGER, KATHERINE WOODRUFF, VICTOR C. LEWIS, WALTER BOOTH, AND TARICK KHADRA

The Department of Health and Exercise Science, Furman University, 3300 Poinsett Highway, Greenville, South Carolina 29613.

ABSTRACT

The purpose of this study was to measure the relative contributions of 4 hip and thigh muscles while performing squats at 3 depths. Ten experienced lifters performed randomized trials of squats at partial, parallel, and full depths, using 100–125% of body weight as resistance. Electromyographic (EMG) surface electrodes were placed on the vastus medialis (VMO), the vastus lateralis, (VL), the biceps femoris (BF), and the gluteus maximus (GM). EMG data were quantified by integration and expressed as a percentage of the total electrical activity of the 4 muscles. Analysis of variance (ANOVA) and Tukey post hoc tests indicated a significant difference ($p < 0.001$*, $p = 0.056$**) in the relative contribution of the GM during the concentric phases among the partial- (16.9%*), parallel- (28.0%**), and full-depth (35.4%*) squats. There were no significant differences between the relative contributions of the BF, the VMO, and the VL at different squatting depths during this phase. The results suggest that the GM, rather than the BF, the VMO, or the VL, becomes more active in concentric contraction as squat depth increases.

Key Words: resistance training, biceps femoris, vastus medialis, vastus lateralis, gluteus maximus

Reference Data: Caterisano, A., R.F. Moss, T.K. Pellinger, K. Woodruff, V.C. Lewis, W. Booth, and T. Khadra. The effect of back squat depth on the EMG activity of 4 superficial hip and thigh muscles. *J. Strength Cond. Res. 16(3):428–432. 2002.*

Introduction

Recently, in the resistance training literature there appears to be a growing interest in the effect of exercise variation on muscle activity patterns during standard lifts. These studies have traditionally used electromyography (EMG) as the primary method of identifying muscle group contribution while comparing different body positions during a lift. Studies on grip width variation in the bench press (1), as well as several studies on variations in the weighted back squat (3, 8, 9), have focused on testing both published and anecdotal information on the effects of changing specific variables in the lifting technique.

The weighted back squat appears to be one of the more popular resistance exercises tested for muscle group involvement with variation in the lifting technique. McCaw and Melrose (3) found that variation in stance width during the squat did not affect isolation of muscles in the quadriceps, which is contrary to what many weight lifters believe. In an earlier study Signorile et al. (8) suggested that foot position variation during the parallel squat did not affect quadriceps muscle use patterns. Wretenberg et al. (9) evaluated 2 squatting depths and bar placement as variables in muscle group involvement in 2 groups of trained subjects. Their conclusions suggested greater thigh muscle activity among the subjects performing the ''low-bar'' squat than in the group using the ''high-bar'' technique. They also reported differences in peak muscular activity in the rectus femoris when comparing a parallel squat with a deep squat. However, they attribute this to differences in ''forward lean'' among the power lifters in the study, who were bigger in size and lifted heavier weights than did the Olympic style lifters, who lifted much lighter loads. During the squatting depth portion of the study, Wretenberg also reported no significant difference in muscle activity in the other thigh muscles, including the vastus lateralis (VL), and the long head of the biceps femoris (BF). This last point is interesting because a popular weight training text by Pauletto suggested that a deeper squat will activate the hamstrings more than a partial squat can (6).

In reviewing previous research on variation in the weighted back squat, it appears that monitoring the activity of the gluteus maximus (GM) might help explain the differences in thigh muscle activity at different squatting depths. Many experts feel that the GM is a key prime-mover muscle in the squat and should be included in a surface electrode EMG analysis of the lift (4, 5). The purpose of this study was to test the effect of 3 different squatting depths on the relative contributions of 4 hip and thigh muscles during the weighted back squat.

Methods

Experimental Approach to the Problem

Pilot data collected during the initial phase of this study revealed some of the same methodological concerns stated in the Introduction. In our attempt to normalize the data with a 1 repetition maximum (1RM) squat, the forward lean problems observed in the pilot trials among our subjects were found to be similar to those reported previously (9). The fatiguing effect associated with heavy resistance (e.g., 1RM) was also a concern because our research design was devised using the same subject for all squatting depths. We also decided to test each subject in 1 session to avoid the potential error associated with the exact replacement of electrodes in multiple data collection sessions. To prevent these potential sources of data variability, our approach was to avoid normalizing the data to a 1RM and instead to compare the electrical activity of each muscle with the total electrical activity of all the 4 muscles tested using submaximal workloads. In other words, because we were most concerned with the relative contribution of each muscle compared with that of the other 3, this approach appeared to be a justifiable alternative when compared with the potential problems associated with normalizing the data using a 1RM.

Selecting the muscles to be monitored was another concern in the present study. Recognizing that the GM has not been monitored in previous studies, this muscle was chosen in light of past research, which suggests that it is an important muscle in weighted back squats (4, 5). Our pilot data indicated that the clearest EMG signal was attained in subjects who possessed a relatively low percentage of body fat (e.g., ≤10%). The other 3 muscles (VL, vastus medialis [VMO], and BF) were selected because these muscles were often targeted for development via back squats, according to most sources (4–7).

Subjects

Ten experienced male weight lifters volunteered as subjects for this study. Descriptive characteristics of the subjects were as follows: age = 24.3 ± 5.6 years, body mass = 86.1 ± 11.2 kg, height = 182.6 ± 6.9 cm, and estimated percent body fat = 6.1 ± 1.8 % (mean ± *SD*). All subjects had an extensive training history with free weights (≥5 years experience), and all had experience in performing at all the squatting depths tested, including full squats (≈0.79 rad at the knee joint), in their workouts. The subjects read and signed informed consent forms, and the Furman University Human Subjects Review Board approved all the procedures.

Experimental Procedures

Two days before testing, each subject underwent a familiarization session in which all 3 squatting depths were practiced with a weight equivalent to between 100 and 125% of each subject's body weight. Each subject chose a weight that was commensurate with his ability to perform the 3 squatting depths with a proper and consistent technique, within the limitations of standard barbell weight configurations. On the day of testing, each subject performed a standardized warm-up (nonresistant movements, light-weighted squats and stretching) and was prepared for randomized trials, with all trials being performed in 1 session. Four superficial muscles of the right hip and thigh were cleaned and abraded to reduce interelectrode resistance. Three EMG surface electrodes (disposable silver–silver chloride electrodes placed in a bipolar configuration 2.5 cm apart, plus a reference electrode) were placed on the bellies of each muscle. The muscles tested were the VL, the VMO, the BF, and the GM. Subject preparation also included the affixing of reflective joint markers on all the visible joints of the right side of the body (hip joint, knee joint, ankle joint, lateral aspect of the calcaneus, and lateral fifth metatarsal), as well as on the center of the bar, for a side-view filming of each trial (Panasonic AG-188U filming at 60 fields per second interfaced with a Gateway E-4200 using the Peak Motus Measurement system, Peak Performance Technologies, Englewood, CO; video taping speed of 60 Hz). This 2-dimensional spatial model of video analysis was set up to insure proper depth on each squat. In addition, all trials were performed with the subject standing on a force platform (AMTI LG6-4-200, Advanced Mechanical Technology, Inc., Watertown, MA), with feet a shoulder width apart with 3 forces and 3 moments measured (Fx, Fy, Fz, Mx, My, Mz). The force plate data were sampled at 2,000 samples per second (4,000 gain; Butterworth filter). To insure the precise location of the exact start and end of each phase of the lift (downward movement involving eccentric muscle contractions, upward movement involving concentric muscle contractions), the digitized video data were synchronized with the EMG and force plate data by computer.

The EMG activity of each muscle was measured using the Biopac system EMG (BIOPAC Systems, Inc., Santa Barbara, CA), with a high-pass frequency filter, and the bipolar electrode system. Trials were randomized to control for order effect, and each subject performed 3 repetitions of weighted back squats with the bar placed across the top of the posterior deltoids. After a warm-up routine the experimental trials were performed with a fixed weight equivalent to 100–125% of each subject's body weight. Each subject was al-

Table 1. Percent contribution (mean ± *SD*) of each thigh muscle during the upward (concentric) phase of the squat for mean integrated electromyographic analysis data.

Thigh muscle	Partial squat (%)	Parallel squat (%)	Full squat (%)
Biceps femoris	13.37 ± 6.97	15.35 ± 10.12	15.01 ± 7.91
Gluteus maximus	16.92 ± 8.78*	28.00 ± 10.29**	35.47 ± 1.45*
Vastus medialis	30.88 ± 16.18***	18.85 ± 8.76	20.23 ± 8.10
Vastus lateralis	38.82 ± 17.37	37.79 ± 13.37	29.28 ± 10.72

* $p < 0.01$.
** $p = 0.056$.
*** $p = 0.07$.

Table 2. Percent contribution (mean ± *SD*) of each thigh muscle during the downward (eccentric) phase of the squat for mean integrated electromyographic analysis data.

Thigh muscle	Partial squat (%)	Parallel squat (%)	Full squat (%)
Biceps femoris	8.77 ± 3.51	6.85 ± 3.10	9.32 ± 8.19
Gluteus maximus	13.05 ± 7.66	10.91 ± 4.22	13.03 ± 6.67
Vastus medialis	39.84 ± 10.26	43.25 ± 10.61	43.21 ± 12.50
Vastus lateralis	38.34 ± 7.12	39.00 ± 12.42	34.61 ± 10.30

lowed at least 3 minutes of rest between trials to minimize fatigue as a contaminating variable. The independent variable within each trial was as follows: (a) partial squats in which the angle between the femur and the tibia was approximately 2.36 rad at the knee joint, (b) parallel squats in which the angle between the femur and the tibia was approximately 1.57 rad at the knee joint, and (c) full squats in which the angle between the femur and the tibia was approximately 0.79 rad at the knee joint. Each subject was also instructed to maintain a consistent upper-body position for each trial. An investigator provided verbal cues for each subject when they were at the proper squatting depth, and proper depth was verified by cinematography analysis from the data collected during filming. If it was determined that proper depth was not achieved or that upper-body lean was excessive (>0.17 rad), that trial was replaced into the random draw to be repeated. This affected only 1 subject in 1 trial in the present study.

Statistical Analyses

EMG data were collected during both the concentric and the eccentric phases of each squat, quantified by integration, and expressed as both peak and mean electrical activity for each phase of the lift. Data from each muscle were normalized by being expressed as a percent contribution to the total electrical activity of all the 4 muscles tested. Although other similar studies have normalized data relative to some maximal effort, our approach was designed to avoid the upper-body deviations, reported in previous work (9), that occurred as the subjects changed their upper-body position at different squatting depths with maximal resistance. The data from the 3 repetitions at each squatting depth were averaged to minimize the potential variation from repetition to repetition. A repeated-measures ANOVA (4 × 3 factorial; muscle group by squatting depth) with a Tukey post hoc test was used to determine the statistical significance of differences in the electrical activity of each muscle tested during each trial.

Results

The results of the integrated electomyographic analysis (IEMG), calculated as the percent contribution of each muscle to the total electrical activity of the 4 thigh muscles monitored, are presented in Tables 1–4. Table 1 includes data on the upward (concentric) phase of the squat, in which the average IEMG of each muscle group was reported. Table 2 represents the downward (eccentric) phase of the lift with the average IEMG data. Tables 3 and 4 represent the peak IEMG values for the concentric and eccentric phases of the lift, respectively.

Discussion

The results of this study suggest that the GM is the muscle group that displays the most varied contribution during the concentric phase of the weighted back squat among the 3 squatting depths tested. The other 3 muscles monitored (BF, VMO, and VL) appear to show more consistency during the concentric phase of weighted squats at these squatting depths, relative to

Table 3. Percent contribution (mean ± *SD*) of each thigh muscle during the upward (concentric) phase of the squat for peak integrated electromyographic analysis data.

Thigh muscle	Partial squat (%)	Parallel squat (%)	Full squat (%)
Biceps femoris	26.02 ± 9.67	26.92 ± 10.90	19.35 ± 6.50
Gluteus maximus	26.81 ± 8.02	27.41 ± 13.83	40.50 ± 13.83*
Vastus medialis	26.70 ± 7.34	28.85 ± 9.97	19.29 ± 6.20*
Vastus lateralis	20.46 ± 8.37	17.45 ± 12.43	20.86 ± 9.37

* $p < 0.05$.

their respective contribution to the lift. The 1 exception to this is the average IEMG activity of the VMO when comparing the partial squat with the other 2 depths. The VMO contributes 30.88% to the total electrical activity of the thigh during the partial squat; yet, it contributes only 18.85 and 20.23% during the parallel and full squats, respectively. This difference was not statistically significant ($p = 0.07$). Also, when considering peak IEMG activity, the VMO is significantly less active in the full squat (19.29%, $p < 0.05$) than in the other 2 squatting depths (parallel at 28.85%, partial at 26.70%). This trend among the VMO data suggests that VMO becomes more of a contributor, in terms of electrical activity, in the partial squat depth but less so during a full squat. During the eccentric phase of the weighted back squat, the relative contributions of these 4 muscle groups at the 3 depths tested were not statistically different for both average and peak IEMG data.

The results of the present study are consistent with the other reported results in the literature. Schaub and Worrell (7) evaluated the relative contributions of several muscle groups that included the VL and the VMO during a parallel, isometric squat and found no statistical difference between those 2 muscles of the quadriceps. Isear et al. (2) examined muscle group contribution during an unloaded squat and suggested that hamstring EMG activity is relatively low when compared with the EMG activity of the quadriceps. Wright et al. (10) also found that hamstring activity during the squat is minimal. Although the latter 2 studies did not include a variety of squatting depths in their designs, the low levels of electrical activity reported in the hamstrings were similar to the results of the present study.

Wretenberg et al. (9) investigated squatting depth as an independent variable in their research design and examined 2 variations in the lift (parallel vs. full squats). Their results were similar to those of the present study because they reported no significant difference in muscle activity in the VL, the VMO, and the BF between the 2 squatting depths. Their study did not monitor the electrical activity of the GM in the design.

In conclusion, the results of our study support the theory that increasing the squatting depth (from a partial [≈2.36 rad at the knee joint] to a parallel [≈1.57 rad at the knee joint] to a full squat [≈0.79 rad at the knee joint]) has no significant effect on the relative contribution of the BF to the total electrical activity of the major muscles involved in the lift. The activity of the VL and the VMO also appears to be fairly consistent across the 3 depths tested, with the exception of those variations reported in the VMO. The primary difference appears to be in the EMG activity of the GM among these 3 squatting depths.

Practical Applications

Although many popular lay publications and anecdotal information suggest that the hamstring muscles are more active during a deep squat, the results of the present study suggest otherwise. The BF does not appear to be more active as squatting depth increases. It appears to be the GM rather than the BF that becomes progressively more active as squatting depth increases from partial to full. It should also be noted that submaximal weights were used in this research design, so the results may only apply to submaximal weights

Table 4. Percent contribution (mean ± *SD*) of each thigh muscle during the downward (eccentric) phase of the squat for peak integrated electromyographic analysis data.

Thigh muscle	Partial squat (%)	Parallel squat (%)	Full squat (%)
Biceps femoris	23.41 ± 11.16	23.94 ± 12.98	27.94 ± 10.85
Gluteus maximus	27.74 ± 16.36	32.80 ± 17.77	25.57 ± 13.40
Vastus medialis	26.90 ± 7.98	23.56 ± 7.41	25.15 ± 14.10
Vastus lateralis	21.94 ± 12.46	19.68 ± 12.88	21.34 ± 9.65

used in training. This last point is justifiable because the majority of lifters who perform the weighted back squat typically use submaximal weight in training and in rehabilitation. Perhaps future research could replicate this study using maximal weights to examine the muscle activity patterns at higher training loads and to determine if these heavier weights elicit similar muscle activity as in the present study. Despite the limitations of the study this information may be useful among coaches and trainers for addressing muscle group specificity in designing resistance training programs. Coaches who wish to target specific hip and thigh muscles may find these results especially useful. It may also have relevance for athletic trainers and others who engage in rehabilitating injured athletes or as ''prehab'' for preventing lower-body injuries.

References

1. Clemons, J.M., and C. Aaron. Effect of grip width on the myoelectric activity of the prime movers in the bench press. *J. Strength Cond. Res.* 11(2):82–87. 1997.
2. Isear, J.A., J.C. Erickson, and T.W. Worrell. EMG analysis of lower extremity muscle recruitment patterns during an unloaded squat. *Med. Sci. Sports Exerc.* 29(4):532–539. 1997.
3. McCaw, S.T., and D.R. Melrose. Stance width and bar load effects on leg muscle activity during the parallel squat. *Med. Sci. Sports Exerc.* 31(3):428–436. 1999.
4. McLaughlin, T.M., C.J. Dillman, and T.J. Lardner. A kinematic model of performance in the parallel squat by champion power lifters. *Med. Sci. Sports* 9:128–133. 1977.
5. O'Shea, P. The parallel squat. *Natl. Strength Cond. J.* 7(1):4–7. 1985.
6. Pauletto, B. *Strength Training for Coaches.* Champaign, IL: Leisure Press, 1991.
7. Schaub, P.A., and T.W. Worrell. EMG activity of six muscles and VMO:VL ratio determination during a maximal squat exercise. *J. Sports Rehab.* 4:195–202. 1995.
8. Signorile, J.F., K. Kwiatkowski, J.F. Caruso, and B. Robertson. Effect of foot position on the electromyographical activity of the superficial quadriceps muscles during the parallel squat and knee extension. *J. Strength Cond. Res.* 9(3):182–187. 1995.
9. Wretenberg, P., Y. Feng, and U.P. Arborelius. High- and low-bar squatting techniques during weight-training. *Med. Sci. Sports Exerc.* 28(2):218–224. 1996.
10. Wright, G.A., T.H. Delong, and G. Gehlsen. Electromyographic activity of the hamstrings during performance of the leg curl, stiff-leg deadlift, and back squat movements. *J. Strength Cond. Res.* 13(2):168–174. 1999.

Acknowledgments

This study was supported by a grant from The National Science Foundation.

Address correspondence to Dr. Anthony Caterisano, tony.caterisano@furman.edu.