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ELECTROMYOGRAPHICAL ANALYSIS OF BAREFOOT SQUAT: A
CLINICAL PERSPECTIVE

Thesis submitted in partial fulfillment of Honors

By

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ABSTRACT

The purpose of this study was to compare muscle activation in eight superficial lower limb muscles during execution of barbell back squats while in barefoot and athletic shoe conditions. It was hypothesized that greater muscle activity would be seen when squats were performed in barefoot conditions. Six participants were included in the study (means: 21.33 ± 1.53 years, 170.45 ± 11.33 cm height, 69.85 ± 12.46 kg mass, 3.4 ± 1.40 years training). Each met specific inclusion criteria. Participants came in three separate days for data collection (Day 1 – 1 repetition maximum [1RM] was determined, Day 2 – maximum voluntary contraction tests were held, Day 3 – squat tests performed with two footwear conditions). Squat tests were performed at 60, 70, and 80% of participants' 1RM for each footwear condition and EMG data was recorded for these tests. Paired-sample T-tests were used to see if any differences were present between footwear conditions during eccentric and concentric phases of the squat, regardless of intensity. To test for differences between eccentric and concentric phases of the squat by intensity, 2x3 repeated measure ANOVAs were performed. Results showed some statistical difference between footwear conditions for two muscles in eccentric phase and no statistical significance for difference in concentric phase when compared without regard to intensity. When comparing footwear conditions at each intensity, main effects, as well as statistical significance, were found between footwear conditions in the eccentric phase. Main effects, but no statistical significance, were found in the concentric phase. The results indicate that EMG activity is greater for certain lower extremity muscles during the eccentric portion of a squat when under barefoot conditions.

INTRODUCTION

Squatting exercises are often used in the strength and conditioning and rehabilitation communities. Athletes and recreationally active individuals of all skill and fitness levels employ squat exercises to further performance. Statements issued by the National Strength and Conditioning Association maintain that “the squat exercise can be an important component of a training program to improve the athlete’s ability to forcefully extend the knees and hips, and can considerably enhance performance in many sports.” The paper also makes a point that “the squat exercise is not detrimental to knee joint stability when performed correctly” (Chandler & Stone, 1991). Squat exercises are also used to promote strengthening and stabilization in a number of rehabilitative protocols for injured and post-operative persons (Ross, Denegar, & Winzenried, 2001; Thein & Brody, 1998; Wilk, Macrina, Cain, Dugas, & Andrews, 2012).

The popular barbell back squat variation has received a great deal of interest in research studies. Variables including kinetics, kinematics, stance, footwear conditions, and muscle activity associated with this technique have been assessed in both athletic and clinical populations (Paoli, Marcolin, & Petrone, 2009; Signorile, Kwiatkowski, Caruso, & Robertson, 1995). No significant differences were found in a study examining electromyographical activity of the lower limb with varied foot placements during back squats (Signorile, et al., 1995). Another study also found that alterations in squat stance width created non-significant changes in EMG activity of thigh muscles, with the exception of the gluteus maximus (Paoli, et al., 2009). With the results of these studies in mind, there does not seem to be a difference in the electrical activity of working muscles when foot placements and stance widths are varied.

The squatting technique performed by weightlifters is typically executed while wearing specially designed weightlifting shoes. This shoe type differs from other athletic footwear in that

it offers non-compressible sole, a raised wedge-shaped heel, and slip-resistant material on the bottom (Davis, 2012). While weightlifting shoes, and even athletic shoes, are the typical choice for use during squat exercises, a recent trend of barefoot squatting has been implemented in strength and conditioning regimens. The basis of this variation has been the idea of achieving improved stability and enhancing force generation without compromising squatting technique (Shorter, Lake, Smith, & Lauder, 2011). Claims have been made that the cushioning provided in many athletic shoe types causes alterations in the body's natural center of balance and that the shoe-cushion displacement under the foot creates unstable surfaces, compromising squatting efficiency and safety during lifting exercises (Kilgore & Rippetoe, 2006). Squatting barefoot is believed to "increase strength in small muscles in the feet and increase ankle joint mobility" (Hadim, 2009). These factors are believed to improve balance and ankle movement during the squat technique, thereby providing better capability to execute the motion. However, many statements are made without scientific evidence and need support.

There have been investigations into the safety of barefoot squatting techniques and the efficacy of such techniques to enhance squat performance. One such study found that back squat performance was altered when participants completed 80% of their 1RM in three separate footwear conditions (Shorter, et al., 2011). The investigators tested for peak power and found the condition using a popular minimalist shoe as having the lowest peak (1254.64 W/Kg) and average (667.93 W/Kg) power performance values with barefoot and shod conditions following; barefoot with peak and average power values of 1374.48 W/Kg and 735.58 W/Kg and shod conditions having peak and average power values of 1627.67 W/Kg and 823.17 W/Kg (Shorter, et al., 2011).

Studies have explored muscle activation during a barbell squat and the kinematic comparisons of squat technique with various footwear conditions during a barbell back squat, but these variables have not been combined to assess the influence of different footwear on lower limb muscle activity. Therefore, the purpose of this study was to compare muscle activation of eight superficial lower limb muscles during barefoot and athletic shoe conditions of barbell back squats. It was hypothesized that greater muscle activity would be seen when squats were performed in barefoot conditions. Outcomes of this study may help provide better understanding of the muscles' electrical activity when subjected to different footwear conditions. This, in turn, might help athletes and clinicians in selecting the most appropriate footwear condition for training or rehabilitation situations.

REVIEW OF LITERATURE

The National Strength and Conditioning Association released a position statement in 1991, comprised of nine points regarding the squat exercise. The statement and the following review of literature accompanying it addressed proper squat technique, safety and benefits of the squat exercise, importance of performing the squat in training to optimize sport performance, and support for the idea that blame placed on weightlifting, specifically that attributed to squatting, may truly be caused by a number of other factors (Chandler & Stone, 1991).

A number of variables are considered in weightlifting and squat-specific studies. Muscle activation during these exercises is one component pertinent to the current study. Muscle activity has been examined a number of times in conjunction with the squat exercise and has been subjected to a variety of protocols and analyses. Electromyography (EMG) has been heavily used to collect data in such studies. Alves, Oliveira, Junqueira, Azevedo, and Dionisio (2009) completed a study

focusing on EMG patterns during squats performed with and without a decline. On a horizontal surface and a declined surface of 25 degrees, participants performed squats from 0 to 70 degrees of knee flexion for the descending phase of the squat and from 70 to 0 degrees for the ascending phase. Though statistically non-significant, the results showed greater muscle activation in the standard squat. The pattern of muscle activation, however, showed no significant difference and was similar between the standard and decline squats (Alves, et al., 2009). Signorile, et al. (1995) examined the effects of different foot positions on electromyographical activity of quadriceps muscles. Participants performed back squats and knee extension exercises under three conditions, toes pointed outward, straight ahead, and inward. While knee extension data showed more EMG activity for all superficial quadricep muscles when participants' feet were externally rotated, the study showed no significant differences in muscle activations with changes in foot position for the squat exercise. It was concluded that changing foot positions during the squat was not necessary to try to promote additional gains in muscle activation (Signorile, et al., 1995). Stance width and bar loads were variables considered in a study by Paoli, et al. (2009). Here, researchers used three stance widths based on greater trochanter distance (GTd) (110, 150, and 200 percent of GTd) and three bar loads (0, 30, and 70 percent of 1RM). Results showed greater muscle activity for each muscle as the bar load increased from 0 to 70% of 1RM. For seven of the eight tested muscles, no statistically significant differences were observed between stance widths at any bar load. For the one remaining muscle, gluteus maximus, significant difference was observed, especially as bar load and GTd increased (Paoli, et al., 2009).

While some studies have focused on the effects of varied technique differences on squat performance and muscle activation, some writings focus on promoting footwear as a key concept to promote better squatting and weightlifting. There are a number of articles stating what shoes

are best to use, and why (Davis, 2012; Kilgore & Rippetoe, 2006; Hadim, 2009). Davis insists that shoes used for weightlifting need to have “hard, non-compressible soles” and fit properly where the foot does not move freely in the shoe, but not so tight as to cause discomfort (Davis, 2012). Kilgore and Rippetoe provide similar statements and include that soles of non-weightlifting shoes (running shoes) “will absorb and dissipate a large amount of the force generated against the floor that should be directed toward moving the weight” (Kilgore & Rippetoe, 2006). In addition to the recommended weightlifting shoe, each mentions alternative shoe types. Kilgore and Rippetoe (2006) promote flat-soled shoes specifically for powerlifts, but discourage their use in squatting due to the need for greater flexibility while wearing them. Davis and Hadim, however discuss barefoot squatting. Davis (2012) states that barefoot squatting may be ideal for deadlifts as it provides less distance for the bar to move from the ground to required lift height. Hadim (2009) mentions that barefoot squats help strengthen small muscles in the feet and promote ankle movements. Of the three, this article is the only one to mention a safety risk of barefoot squatting, that being the danger of dropping a weight on the lifter’s foot (Hadim, 2009). Though each of the articles provides advice on which shoes to wear in weightlifting, mentioning certain shoes (or none) for the squat technique, none of the articles are peer-reviewed nor do they include support from scientific evidence. Since such articles exist, it would be beneficial to have studies completed regarding footwear effects on the squat exercise.

Few studies have been completed to test the effects of varied footwear conditions, especially inclusive of a barefoot squat, on squatting performance, kinematics, and muscle activation. One study did investigate footwear effects on squat performance (Shorter, Lake, Smith, & Lauder, 2011). It was hypothesized that performance differences caused by changes in foot-floor interface (using three types of footwear conditions) would provide implications for

squat performance and injury prevention. Researchers analyzed the concentric phase of the squat movement and center of pressure (COP) measurements for a back squat and a jump squat in three footwear conditions (barefoot, Fivefinger minimalist shoe, and indoor training shoes). The study showed little influence of footwear conditions during the jump squat, but peak power values and COP measurements were significantly different in back squat performances, specifically between Fivefinger shoes and training shoe conditions. Peak power and COP were both greater in shod conditions compared to the Fivefinger shoe condition (Shorter, et al., 2011). A study by Sato, Fortenbaugh, Hydock, and Heise (2013) compared the kinematic differences between squats performed barefoot and with running shoes. Data was gathered for peak flexion angles of thigh and trunk segments as well as for hip, knee, and ankle joints. Results were compared to the position statement given by the N.S.C.A. (Chandler & Stone, 1991), two of which were found to be unfavorable and one favorable. It was observed that greater trunk flexion occurred during the barefoot squat and it was more difficult for participants to reach the desired parallel squat position in this condition as compared to the running shoe condition. Both results were unfavorable as they compromised squat technique (Sato, et al., 2013). However, the barefoot condition elicited seven degrees less knee flexion compared to the running shoe condition, something that might prove beneficial in reducing knee torque during lifts.

METHODS

Participants

Participants were all volunteers from healthy young adult population. The age group for these participants was from 18 to 24 years in both genders. The demographic data is listed on table 1. The study protocol was approved by the University's institutional review board, and consent was obtained prior to participation in this study.

There were several criteria that participants needed to meet for study participation:

- 1) All participants must be able to perform barbell back squat at least their body weight worth of external resistance. However, for those people who tested 1 repetition maximum (1RM), and recorded greater than 1.5 times of their body weight, they were excluded from the study.
- 2) All participants have been supervised by qualified strength and conditioning coach on daily basis. The reason for this type of particular criteria is to meet proper back squat technique including keeping feet flat on the floor and ensuring that the thigh segments went below parallel to floor. Self-trained individuals were excluded from the study.
- 3) All participants must have regularly squatted in athletic shoes but not in weightlifting shoes or barefoot. Those people who regularly squat in WL shoes and barefoot could respond differently to the testing sessions as compared to the first time users, thus they were excluded from the study.

Table 1: Demographic data of participants

	Total (N = 6)
Age (year)	21.33±1.53
Height (cm)	170.45±11.33
Mass (kg)	69.85±12.46
Training years (year)	3.4±1.40
Estimate 1 RM (kg) with shoes	102.17±18.65
Estimate 1 RM (kg) with barefoot	98.5±21.17

Instruments

An 8-channel Noraxon TeleMyo 2400T (Noraxon USA, Inc. Scottsdale AZ) was used to collect maximum voluntary contraction (MVC) data and electrical activity of lower extremity muscles during the squat tests. Unit specifications included a differential input impedance of greater than 10 M Ω , a gain of 1000, and a common-mode rejection ratio of greater than 100 dB at 60 Hz. The EMG signals were high pass filtered with 10 Hz and low pass filtered with 500 Hz. The device was interfaced with its analog input/output 2400R G2 receiver (Noraxon USA, Inc., Scottsdale AZ). A bipolar Ag/AgCl surface electrode with an inter-distance of 2 cm was placed in parallel over the belly of tested lower extremity superficial muscles. Myosearch 2.11.16 software (Noraxon USA, Inc., Scottsdale AZ) was used for data processing and analysis. For the visual inspection of separating the eccentric and concentric phases of the back squat, a 60 Hz camcorder (Panasonic, Japan) was synchronized with the unit. Although motion of the squat was recorded to identify where the instantaneous point of concentric movement, motion analysis was not done according to the purpose of the study.

Procedures

There were three meetings with each participant to complete data collection; 1) 1RM test, 2) MVC test, and 3) squat test with two footwear conditions. Each test was separated by at least 72 hrs to recover from the previous testing.

Day1: estimated 1RM squat test

Participants reported to the sport science laboratory for the 1 RM test. Actual 1RM was estimated based on a 4-6 RM effort back squat (Dohoney, Chromiak, Lemire, Abdie, & Kovacs, 2002; Sato & Heise, 2012). Warm-up consisted with dynamic stretching, 20 jumping jacks, and

back squat with light weights and lasted a no more than 10 minutes. After the initial warm up sets of 4-6 repetitions were performed until a maximum load was obtained for 4-6 repetitions. A minimum of 2 minutes rest was given between sets. The mean and standard deviation of the estimated 1 RM for all participants is shown in Table 1. It is important to note that this test was done with regular running shoes given a fact that all participants typically train with running shoes.

After the test, an identical 4-6 repetition maximum testing was completed with the barefoot condition. The primary reason for conducting 1RM test for barefoot condition is to identify the 1RM while squatting barefoot. Based on the pilot study, barefoot squat is an unfamiliar task for all participants and speculation was that barefoot squat 1RM would be lower than the running shoe squat 1RM. This was also to eliminate possible overestimating the intensity during the barefoot squat on 60, 70, & 80% of 1RM.

Day 2: MVC test

Participants reported to the athletic training room for MVC test. An isokinetic dynamometer (125AP, KinCom, TN USA) was set to isometric mode thus allowing participants to exert maximal force during the MVC test. Participants sat on the device with straps around the body to ensure the isometric contraction of tested muscles. First, the investigator prepared tested muscle locations by cleaning up skin and attaching electrodes. The sites for electrode placement were prepared by abrading the skin with fine sandpaper and cleansed with 70% isopropyl alcohol. Shaving excess hair was done if necessary for some participants. Dual disposable surface electrodes described above, were placed on selected superficial muscles to collect maximal electrical activity of each muscle.

There were total 8 electrodes attaching to 8 different muscles on one side of the lower limb (right side). Those muscles are 1) vastus medialis considered as medial quadriceps, 2) vastus lateralis considered as lateral quadriceps, 3) semitendinosus considered as medial hamstring, 4) biceps femoris considered as lateral hamstring, 5) medial gastrocnemius, 6) lateral gastrocnemius, 7) tibialis anterior, and 8) peroneus. Electrode placement was determined according to the European Recommendations for Surface Electromyography 2nd edition (Hermens, Freriks, Merletti, Hagg, Stegeman, Block, et al., 1999). After placing all electrodes, participants sat in the dynamometer machine and were secured to the seat to exert an isometric contraction. Order of the MVC tests was 1) leg extension with knee angle at 90° (2 quadriceps muscles), 2) leg curl with knee angle at 90° (2 hamstring muscles), 3) dorsiflexion with knee angle at 180° (anterior tibialis), 4) plantar flexion with knee angle at 180° (medial/lateral gastrocnemius), and 5) eversion with knee angle at 135° and ankle angle at 120° (peroneus). Table 2 shows the order from warm-up leading up to the maximal contraction. Maximal effort of contraction lasted 5 seconds, with the time between the 2nd to 5th seconds (3 seconds) considered as the maximal contraction. The two maximum attempts were averaged for the analysis. After the MVC test, all electrodes were removed and wiped with alcohol.

Table 2: Order of MVC test from warm-up to maximum contraction

Order to MVC test	
1)	50% Effort 3-4 sec contraction
2)	45 seconds rest
3)	75% Effort 3-4 sec contraction
4)	1:30 rest
5)	100% Effort 5 sec contraction
6)	2:00 rest
7)	100% Effort 5 sec contraction

Day 3: squat test with different footwear

As similar to MVC test, the sites for electrode placement were cleaned and prepared by abrading the skin with fine sandpaper and cleansed with 70% isopropyl alcohol. Shaving excess hair was done if necessary for some participants. Identical electrode placements were used for the squat EMG analysis with the other footwear condition.

The back squat task was to perform 60%, 70%, and 80% of 1RM for 1 set of 5 repetitions in both footwear conditions. The two footwear conditions were randomly chosen for each person participating. Participants started out with dynamic warm-up and then squatted with light weights leading up to 60% of 1RM intensity. The standard stance width was slightly wider than shoulder width and toes pointing slightly outward as described by Escamilla et al. (1998). All participants squatted down to a position where thigh segments were below parallel to the floor on each repetition. Participants were familiar with the barbell back squat so that minimal instruction was given such as squat speed being relatively consistent between eccentric and concentric phase. In order to control the consistent rhythm of the squat, a metronome was used and set to 60 beats per minute (Sato & Heise, 2012). The current study used a slow-paced squat, and the participants were instructed to perform it with a rhythm of 3-2 count (3 counts downward 2 counts up). This rhythm was necessary to minimize unnecessary acceleration throughout the squat. A recent study found the influence of squat speeds on selected biomechanical variables (Hanson, et al., 2007). Investigators felt necessary to control all participants' squat speed to avoid high variation of electrical activity from different squat speed. Another study also showed that different squat speeds have been shown to display altered body control, and increases or decreases in the sway of spinal alignment (Granata and England, 2006), in which could create high variance in electrical activity of the tested muscles.

After stretch and warm-up, the participants were set to perform 60% of 1RM with the verbal signal of “3–2–1, go” given by the investigator. After completing 5 repetitions, they placed the barbell back on the squat rack after which the load was changed for each subsequent set to match 70% and 80% of estimated 1RM. The rest period between the set was 2 to 5 minutes depending on the participant’s need.

Data and Statistical Analyses

Myosearch 2.11.16 software (Noraxon USA, Inc., Scottsdale AZ) was used for data processing and analysis. Raw signal was obtained at sampling frequency of 1,500 Hz. The signal was rectified and converted to the average root mean square signal. Then the signal was smoothed using Hanning integrator set to 20 points. From each tested set of 5 repetitions the second, third, and fourth repetitions were considered for analysis by averaging the total of 3 repetitions. The back squat was separated into two portions; eccentric and concentric. The phase was divided by the lowest descent position of the squat visually identified from a recording device.

Upon the data collection, all data were exported to a spreadsheet for data analysis purpose (Microsoft Excel, WA USA). The average EMG values of both eccentric and concentric phases of the squat in tested intensity (60, 70, & 80%) for each muscle were normalized as percentage based on the MVC values. Those percentage values were considered for the analysis of the current study.

To test whether there are differences between footwear conditions in eccentric and concentric phases regardless of intensity, Paired-sample T-tests were conducted on each tested muscle. To test whether there are differences between footwear conditions in eccentric and concentric phases by intensity, 2x3 (footwear x intensity) repeated measure ANOVAs were conducted. When

statistical significance was identified from this analysis, post hoc test were ran to identify where the significance come from. The statistical analysis is performed by PASW software using alpha level of 0.05 (IBM Inc, New York, NY).

RESULTS

Footwear Comparison Regardless of Intensity

Footwear conditions (running shoes and barefoot) in eccentric and concentric phases of back squat were compared regardless of lifting intensity. In eccentric phase, biceps femoris ($T(1,17)=2.523, P<.05$) and tibialis anterior ($T(1,17)=-2.565, P<.05$) showed statistically significant difference between two footwear conditions. Other muscles showed a trend of differences; vastus medialis ($P=.13$), vastus lateralis ($P=.09$), semitendinosus ($P=.14$), medial gastrocnemius ($P=.14$), and lateral gastrocnemius ($P=.10$), but did not reach statistical significance. In concentric phase, no muscles showed statistical significance and few showed trends; vastus medialis ($P=.11$) and tibialis anterior ($P=.11$). Other muscles showed P value of over .30 indicating that changing footwear did not influence the way superficial lower extremity muscle activated in concentric action.

Footwear Comparison at Each Intensity

Footwear conditions were compared at each intensity (60, 70, and 80%). In eccentric phase, there were main effects on intensity as the following muscles showed statistically significant difference between the footwear conditions; vastus lateralis ($F(1,5)=10.03, P<.05$), biceps femoris ($F(1,5)=16.46, P<.05$), medial gastrocnemius ($F(1,5)=8.80, P<.05$), lateral gastrocnemius ($F(1,5)=9.96, P<.05$), and peroneus ($F(1,5)=7.67, P<.05$). This indicates that as

the intensity gets higher, the level of electrical activity in the muscle gets higher. In concentric phase, there were main effects on intensity change on only semitendinosus ($F(1,5)=7.26, P<.05$). Although there were several main effects on intensity change, only trends were found in difference in main effects of footwear condition and no statistical significance was captured. In eccentric phase, vastus medialis ($P=.17$), vastus lateralis ($P=.19$), biceps femoris ($P=.16$), and tibialis anterior ($P=.16$) showed a trend of difference between footwear conditions. In concentric phase, vastus medialis ($P=.13$) and tibialis anterior ($P=.08$) were the only two muscles showed a trend of difference between footwear conditions.

Table 2: Electrical activity of lower extremity muscle at 60%.

Muscles	Running shoes		Barefoot	
	Concentric	Eccentric	Concentric	Eccentric
Vastus medialis	80.73±28.04	74.36±45.94	81.98±31.40	58.91±19.37
Vastus lateralis	103.42±68.26	67.26±46.47	105.61±83.40	67.03±54.63
Semitendinosus	16.34±10.72	10.77±6.60	17.82±11.38	12.11±9.36
Biceps femoris	51.74±24.71	18.15±7.99	52.94±47.64	14.97±4.26
Medial gastrocnemius	30.43±19.66	16.34±6.94	38.57±23.75	16.05±9.02
Lateral gastrocnemius	33.09±34.10	27.48±36.60	36.58±28.61	19.74±16.78
Tibialis anterior	32.88±20.05	30.73±25.30	27.36±19.33	32.96±28.11
Peroneus	35.74±32.26	24.93±26.72	41.46±36.67	28.11±37.64

Table 3: Electrical activity of lower extremity muscle at 70%.

Muscles	Running shoes		Barefoot	
	Concentric	Eccentric	Concentric	Eccentric
Vastus medialis	90.14±46.72	57.63±26.09	87.84±42.45	55.16±21.29
Vastus lateralis	117.58±82.35	74.81±53.82	111.64±82.49	67.68±44.30
Semitendinosus	23.76±17.60	12.91±7.82	20.88±11.29	16.14±14.63
Biceps femoris	68.93±45.47	22.53±8.57	59.54±46.29	19.66±8.35
Medial gastrocnemius	38.84±24.26	23.25±14.12	32.05±14.83	15.72±4.41
Lateral gastrocnemius	38.89±35.17	27.97±34.01	35.25±32.16	22.90±26.19
Tibialis anterior	31.93±21.31	29.83±20.78	32.74±22.25	37.07±29.43
Peroneus	49.71±47.25	30.08±33.57	41.89±36.83	24.82±25.84

Table 4: Electrical activity of lower extremity muscle at 80%.

Muscles	Running shoes		Barefoot	
	Concentric	Eccentric	Concentric	Eccentric
Vastus medialis	103.95±42.44	68.04±23.42	91.66±47.69	57.49±26.14
Vastus lateralis	122.44±96.80	79.12±57.28	117.52±95.69	72.86±52.40
Semitendinosus	28.14±21.03	16.13±9.89	26.98±15.61	19.56±16.14
Biceps femoris	79.29±64.86	24.08±8.53	73.24±64.49	20.19±8.42
Medial gastrocnemius	43.17±33.89	22.83±10.70	35.22±16.41	20.41±8.74
Lateral gastrocnemius	46.74±52.95	30.94±36.50	39.66±33.77	26.46±24.40
Tibialis anterior	37.63±17.73	28.81±18.74	33.47±23.88	36.06±29.58
Peroneus	52.54±57.10	30.87±32.36	52.33±53.80	31.40±37.96

DISCUSSION

The purpose of this study was to determine the activation of specific superficial muscles of the lower extremity when performing a back squat in athletic shoe and barefoot conditions. Significant differences were seen in the activation of two muscles (biceps femoris and tibialis anterior) between footwear conditions during the eccentric portion of the squat, while no muscles showed significant differences in activation during the concentric portion. When compared by intensity, main effects between footwear conditions were observed for a number of muscles during the eccentric portion of the squat and only for one muscle during the concentric movement.

Observations of this study are in accordance with previous findings. Dionisio, Almeida, Duarte, and Hirata (2006) also reported greater activation of the tibialis anterior during the downward squat movement. Tibialis anterior is a muscle significant for dorsiflexion of the foot and it has been described as a muscle that initiates squat movement (Alves, et al., 2009). Additionally, it serves as an ankle joint stabilizer during the squat (Alves, et al., 2009). Considering this role and observing greater activation of tibialis anterior in the barefoot

condition could indicate that barefoot conditions produce decreases in stability features, thereby requiring more muscle response in the eccentric phase of squatting to maintain stability.

Most muscle activation difference between shoe conditions was observed during the eccentric portion of the squat. For this reason, an eccentric portion of the squat protocol could be used to activate and strengthen the muscles. This would not be the only time eccentric exercise has been promoted as a way to strengthen muscles. One study observed greater potential for score improvement on an assessment questionnaire when participants completed an eccentric phase squatting protocol as compared to a step protocol (Young, Cook, Purdam, Kiss, & Alfredson, 2005). The study methods included the athletes taking the Victorian Institute of Sport Assessment (VISA) questionnaire, a short assessment of symptoms and tests of function for athletes to play a sport (Young, et al., 2005). The researchers indicated that there could be potential increases of twenty points or more on the questionnaire after completion of the eccentric phase squatting protocol. In another study, researchers used eccentric loading in a resistance exercise program as part of an assessment of methods to manage tibialis posterior tendinopathy. Compared to other treatment groups, those wearing orthoses only and those with orthoses and completing a concentric exercise program, participants of the orthoses and eccentric exercise protocol showed the largest change in scores reported for pain and functionality after the intervention (Kulig, Reischl, Pomrantz, Burnfield, Mais-Requejo, Thordarson, & Smith, 2009). The referenced studies did not provide changes in footwear, specifically inclusion of barefoot procedures. This should be taken in to consideration when comparing results of these studies to a new barefoot protocol.

The current study provides some evidence on the effects of barefoot squatting on muscle activation and, though there may be implications toward clinical applications, there were

drawbacks to the study. The participants for the study were athletes with a required length of weight training and lifting experience. Additionally, the inclusion criteria for the squat made the participant diversity limited. This might make the study less generalizable to a clinical population, something that should be taken into consideration by any clinician looking to evaluate the effectiveness of loading during the eccentric phase of a squat for a rehabilitation program. Performing the squat movement, in athletic shoes or barefoot, with prior knowledge of lifting technique might produce less change in squatting mechanics, thereby promoting squat effectiveness and safety, something that may not occur in a clinically set population.

Increased lower extremity weakness, often found in clinical populations, can contribute to excessive displacement of the knee, causing varus knee movement (Bell, Padua, & Clark, 2008). This might present in such a population that unfamiliar with squat techniques, especially if subjected to an unsupported barefoot condition. An article by Gross and Foxworth (2003) points out that significant pronation of the foot can also contribute to medial knee displacement. Foot orthoses have been discussed as ways to address this foot displacement and have been used in a number of research studies concerning alignment and muscle activation (Gross & Foxworth, 2003; Murley, Mendorf, Menz, & Bird, 2009; Stacoff, Reinschmidt, Nigg, van den Bogert, Lundberg, Denoth, & Stussi, 2000). As previously mentioned, orthotics have been used specifically alongside eccentric phase exercise designs (Kulig, et al., 2009) for study in the treatment of pain.

Change in foot position due to orthotics has been shown to trigger alterations in muscle activation (Murley & Bird, 2006), a factor that could be pertinent to the results of the current study. When studies using walking and running were considered, literature reviewed by Murley, et al. (2009) showed orthotic use had significant effects on muscle activation. A study by

Tomaro and Burdett (1993) showed specific increase in activation of the tibialis anterior muscle during gait under orthotic conditions compared to the condition without orthotics. While there is evidence stating that orthotics can influence EMG patterns, there is apparent controversy as to whether foot orthotics change alignment significantly enough to prove this to be the cause of any proposed benefits from wearing the pieces (Groner, 2011). EMG patterns, though significantly different, were inconsistent between individuals in a study by Murley & Bird (2006) and effects produced by orthotics in terms skeletal movement were found to be small and inconsistent in a study by Stacoff, et al. (2000). It is still maintained by some that these small changes are significant and that even verbally reported differences made by those who wear orthotics are indications of alignment changes (Groner, 2011). If foot orthoses do help keep proper alignment of the lower extremity to assist with better squat technique and do not contribute to other detriments of squatting mechanics, it may be likely that these inserts, or athletic shoes with more foot support, and not a barefoot exercise, would be beneficial in clinical programs. This might be especially true with persons more prone to genu valgus or genu varus. Considerations for squat technique and safety would have to be considered with the effects of potential muscle activation from barefoot protocols to benefit clinical patients. Had participants of the current study been tested for knee instability, significant inward or outward movement of the knee, or foot type (pronated, supinated, fore- or rearfoot valgus or varus, etc) more conclusions might have been able to be inferred about eccentric phase based protocols during barefoot squat being used in rehabilitative practices.

Even if eccentric loading for a squat exercise would prove to be beneficial in strengthening the lower extremity muscles, contraindications based on injury, patient ability, and strength would need to be considered before implementing such a protocol. As no known studies have

examined muscle activation of lower extremity muscles during squatting movements under different footwear conditions, additional studies relating to these matters would be suggested. It would be beneficial for future studies to examine the effects of extended barefoot training protocols, with consideration given to ankle joint effects, foot type, and knee valgus or varus tendencies to promote ideas for clinical practice.

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