International Journal of Strength and Conditioning

The Effect of Hip Flexor Tightness on Muscle Activity during the Front Squat: A Pilot Study

Sarah C. Martinez-Sepanski[1], Angie Bowman[2] & Kelton D. Mehls[3]

[1]Department of Human Performance and Sport Sciences, Tennessee State University, Nashville, TN, USA,
[2]Department of Health and Human Performance, Middle Tennessee State University, Murfreesboro, TN, USA,
[3]Department of Athletic Training, Duquesne University, Pittsburgh, PA, USA

ABSTRACT

The purpose of this study was to compare peak and mean surface electromyography (sEMG) in the rectus femoris (RF), gluteus maximus (GM), biceps femoris (BF), semitendinosus (ST) muscles, and GM:BF muscle co-activation ratio during front squat between resistance trained females with and without hip flexor tightness. Peak and mean sEMG was recorded during three repetitions of 75% of one-repetition maximum (1RM) front squat of resistance trained females who either had hip flexor tightness (n = 9) or did not have hip flexor tightness (n = 7). Observed mean sEMG of the GM and BF was used to calculate GM:BF muscle co-activation. The result of the independent samples t-test indicated a statistically significant difference in peak RF (p = .013), peak (p = .001) and mean (p = .045) BF, and GM:BF muscle co-activation (p = .042) between those with and without hip flexor tightness during the ascending phase of a 75% 1RM front squat. The results indicate the RF and BF to be more active in resistance trained females with hip flexor tightness than those without hip flexor tightness during the front squat, potentially lowering GM activation relative to the BF. Fitness professionals should consider providing a hip flexor stretching interventions to prevent over activation of the BF when selecting the front squat as a resistance training exercise.

Keywords: muscle activity, muscle imbalances, resistance training.

INTRODUCTION

Resistance training exercises have long been utilized to target and address muscular weakness. To optimize resistance training exercises, the maximal recruitment of motor units in a targeted muscle is desired. Many recent studies have compared muscle activity during resistance training exercises such as the back squat, deadlift, hip thrust, and front squat (9-11, 17, 20, 26, 29) to help improve exercise prescription of commonly targeted muscles, particularly the gluteus maximus.

When selecting a resistance exercise to train the gluteus maximus (GM), it is paramount to consider the level of muscle activity during different resistance training lifts. Korak and his colleagues (17) found that GM activation was highest in the front squat compared to the back-squat and dead-lift at 75% of a one-repetition maximum (1RM) in resistance trained women. Maximal activation of the GM is customarily emphasized during resistance training programs because it is considered the prime mover at the hip during various weight-bearing activities (18, 22). Correspondingly, a weak or underactive GM may cause lower extremity dysfunction, possibly leading to injury (4, 8).

As mentioned above, appropriate muscle activation patterns of GM is essential for proper human movement. However, poor flexibility has been noted to alter muscle recruitment and distort normal human movement patterns (1, 21). Specifically, restricted hip extension caused by tight hip flexors can inhibit neural drive to the GM (1, 4, 7). Tight and overactive hip flexors can cause altered reciprocal inhibition, where the GM is lengthened and underactive during hip extension. This may lead to muscular imbalances where there is a greater reliance on the synergist, hamstrings, to move the body through hip extension (7-8, 24) otherwise known as synergistic dominance. It has been proposed that synergistic dominance of the hamstrings leads to arthrokinetic dysfunction during sprinting and jumping movements may increase the risk of hamstring injury (3, 8, 24, 28). To the authors knowledge, only one study has observed the possible effects of restricted hip extension on muscle activity in the gluteus maximus:biceps femoris (GM:BF) muscle co-activation ratio in females (21). While the authors noted a decrease in significantly lower GM:BF muscle co-activation ratio in females with hip flexor tightness compared to those without, the only exercise observed was the bilateral air squat.

There has yet to be a study that investigates the effect of tight hip flexors on muscle activation during an externally loaded resistance training exercise and in females. Therefore, the aim of this study was to compare peak and mean sEMG in the rectus femoris (RF), GM, biceps femoris (BF), semitendinosus (ST) muscles, and GM:BF muscle co-activation ratio during front squat between resistance trained females with and without hip flexor tightness. It was hypothesized that females without hip flexor tightness will have higher peak and mean muscle activation of the GM and GM:BF muscle co-activation compared to those with hip flexor tightness.

METHODS

Experimental Approach to the Problem

Surface EMG was recorded during three repetitions of 75% 1RM front squat of resistance trained females who either had hip flexor tightness (experimental group) or did not have hip flexor tightness (control group). During the first visit, after anthropometrics were taken, a certified athletic trainer completed the modified Thomas Test on each subject which was then used as a classification parameter and the subjects were divided into two groups previously mentioned. This was followed by a warm-up and 1RM front squat test (executed by a certified strength and conditioning specialist), where peak sEMG of the GM, RF, BF, and ST was also recorded for normalization procedures. During the second visit, the subjects completed the same warm-up from the first session and completed 75% of their 1RM front squat, where peak and mean sEMG of the GM, RF, BF were recorded.

Subjects

Sixteen healthy resistance trained females (age: 22.19 ± 2.28 years; height: 163.54 ± 6.82 cm; body mass: 69.02 ± 9.66 kg; 1RM: 70.44 ± 17.01 kg) were assigned either to a control (n = 9) or experimental (n = 7) group determined from the modified Thomas Test. All participants were free of any lower body musculoskeletal injury within the past three months and categorized as moderately resistance trained where they have been currently training for the past 3-6 months at a minimum of 2 times per week (13). After the participants were informed of the benefits and possible risks of the protocol, all participants read and signed a written informed consent and PAR-Q+ pre-health screening prior to participation. Participants were recruited from the surrounding community via word of mouth. The Institutional Review Board at Middle Tennessee State University approved this study prior to data collection.

The modified Thomas Test was used to assess hip flexor length. Previous studies have shown that this method of hip extension range of motion (ROM) assessment has good inter-rater reliability (6, 21, 23). A digital inclinometer (Model #12-1057, Fabrication Enterprise Inc. – Baseline Evaluation Instruments, White Plains, New York) was used to measure hip extension ROM during the modified Thomas Test. Inclinometer values greater than 0° (+) indicate that the thigh, a line between the knee and hip joint, was positioned above parallel and relatively flexed. Inclinometer values below 0° (-) indicate that the thigh was below parallel and relatively extended (12). Inclusion criteria for the control group was defined as hip extension ROM greater than 0° below parallel. Inclusion criteria for the experimental (tight hip flexor) group was defined as hip extension 0° degrees or more above parallel (21). The tightest leg was the experimental leg observed during the study. The modified Thomas Test was performed by the by the leader investigator, a certified athletic trainer.

Procedures

Participants were required to attend two sessions session at the university muscle physiology laboratory. Upon attending the first session, participants completed the informed consent and PAR-Q+ pre-health screening questionnaire and were screened for inclusion criteria. If the participants met inclusion criteria for either group, then participant's age, height, and body mass were measured and recorded. Height was measured to the nearest 0.1 cm using a stadiometer (SECA Corporation, Model 222, Germany) and body mass was assessed using a digital scale (Tanita Worldwide, Model BF 522, Arlington Heights, Illinois) to the nearest 0.1 kg. All testing procedures were performed by a certified athletic trainer.

Next, the participants were asked warm-up using a row ergometer (Concept II) at a self-selected pace for 3-5 minutes. Participants then performed 15 repetitions of the front squat using the Smith Machine at a self-selected load where 15-repetitions could be easily completed. Following practice repetitions, the participants one-repetition max (1RM) was assessed following the National Strength and Conditioning Guidelines (NSCA) (13). All testing procedures were performed by the primary investigator, a certified athletic trainer and certified strength and conditioning specialist.

Participants returned for the second session a minimum of 48 hours later to assess muscle activity during the front squat. Kinematic data (angular movement) was measured using wireless goniometers (Biometrics, Newport, UK) that were connected to Trigno Goniometer Adapters both of which were fixated to the skin in the same fashion described for the Trigno Flex sensors following the SENIAM guidelines (25) . The primary purpose of the kinematic data was to identify ascending and descending phases of the front squat. For knee joint angle, the proximal arm was aligned along the femur to the greater trochanter and the distal arm was aligned to the lateral tibia in line with lateral malleolus. All muscle activity and kinematic data was integrated directly into the EMGworks software via wireless adapters provided by the manufacture to ensure proper timing during recording. An external trigger device (Delsys, Natick, MA) was used to initiate and cease data collection. The sEMG data that was collected during the 1RM was used for normalization of muscle activity during the front squat.

Participants performed the same warm-up completed during session 1. Following the warm-up, the participants completed a 1RM, followed by 75% of 1RM front squat. Participants were given 5 minutes of rest between the 1RM and performing 3 repetitions at 75% 1RM. A metronome was used during the front squat for a two second eccentric phase and one second concentric phase. A bungee cord was used to establish the participants' parallel squat depth and the participants were required to touch the bungee with their buttocks on each rep before ascending during all testing procedures (19).

Data Processing

All EMG data was normalized to peak muscle activity during 1RM data collected for each participant to represent muscle activation of each muscle as a percent of peak muscle activity during a 1RM (5,14). Surface EMG data were initially processed using a Nyquist resampling equation at 1000Hz. Data was initially filtered with a 2nd order Butterworth band-pass filter at 20Hz and 450Hz. A root-mean-square algorithm with a 200 ms window was then applied to the filtered data. Goniometer data was to mark and differentiate directional phases during each movement. Trigno Goniometer data was resampled at 1000 Hz, then placed into overlaid format. Upon magnifying this format, exact time points could be recorded for when the subject entered the descending and ascending phase. The time points for when the ascending and descending phases started and ended were recorded. The muscle activity data was then analyzed during the times points that represented the descending and ascending phases of each repetition. The described data processing was performed through EMGworks analysis software (Delsys, Model SC-S08-4.5.3, Natick, MA). All data was then imported into IBM© SPSS© Statistics (IBM Corp. Released 2016. IBM SPSS Statistics for Windows, Version 24.0. Armonk, NY: IBM Corp) where the data was normalized to the peak 1RM values. The gluteus maximus: biceps femoris co-activation ratio was calculated for each participant as described by Mills et al. (21) in SPSS, which is calculated by dividing the mean gluteus maximus activity by the mean biceps femoris activity (gluteus maximus: biceps femoris). Then Descriptive Statistics were run to find the mean co-activation ratio for each group (control vs. experimental). A gluteus maximus: biceps femoris ratio of 1.0 indicates balanced muscular activation, whereas a ratio less than one 1.0 indicates greater activation of the biceps femoris relative to the gluteus maximus.

Statistical Analyses

The IBM© SPSS© Statistics (IBM Corp. Released 2016. IBM SPSS Statistics for Windows, Version 24.0. Armonk, NY: IBM Corp) was used for the statistical analysis. Average peak and mean muscle activity across 3 reps at 75% 1RM was calculated in

SPSS. Descriptive statistics were provided for each participant and be expressed in means + standard deviations. A Shapiro-Wilk test was performed to test for normality and showed that the distribution of GM.Peak.ASC, ST.Mean.DSC, and RF.Peak. ASC departed significantly from normality (p-value < 0.01). All other variables displayed normal distribution. A Wilcoxon Sign-Rank Test was ran for peak GM activity during the ascending phase, Mean ST activity during the descending phase, and peak RF activity during the ascending phase to compare participants with and without hip flexor tightness. For normally distributed variables, independent samples t-tests were conducted to compare participants without hip flexor tightness (n = 9) and participants with hip flexor tightness (n = 7) for of RF, BF, ST and GM peak and mean muscle activity and gluteus maximus: biceps femoris co-activation ratio during 75% 1RM of the front squat. Peak and mean muscle activation were analyzed during the ascending and descending phases of the front squat. Effect sizes were calculated using Hedges' g. The alpha level was set at .05 for all statistical procedures. To control for multiple comparisons, the alpha level was set at .002 using the Bonferroni correction for all statistical procedures.

RESULTS

Peak and mean muscle activity comparisons of the RF, BF, ST, GM those with and without hip flexor tightness can be found in Table 1 and Table 2. The results of a Wilcoxon Sign-Rank Test for peak GM activity during the ascending phase, Mean ST activity during the descending phase, and peak RF activity during the ascending phase displayed no significant differences between those with and without hip flexor rightness. The result of the independent samples t-test indicated a statistically significant difference in peak BF between those with and without hip flexor tightness during 75% 1RM of the front squat. During the ascending phase, peak BF muscle activity in those with hip flexor tightness was significantly higher (p = .001, Hedge's g = 1.92) compared the those without hip flexor tightness. GM:BF co-activation comparisons during the descending and ascending phases of a back squat can be found in Figure 1. No other significant effects were found for peak and mean RF, BF, ST, GM, and co-activation ratios during both the ascending and descending phases of the back squat.

DISUCUSSION

The purpose of this study was to compare peak and mean RF, BF, ST, GM, and GM:BF muscle co-activation in resistance trained females with and without hip flexor tightness during 75% 1RM of the front squat. During both the descending phase, peak BF activity was significantly higher (p = .001) in those with hip flexor tightness compared to those without. No other significant interactions were found. This does not support the original hypothesis that the GM would be significantly more activated in those without hip flexor tightness during the front squat. However, although not significant, our results did demonstrate that females without hip flexor tightness did display higher peak and mean GM activity and GM:BF co-activation ratio. Which may contribute to why the females with tight hip flexors display significantly higher amounts of bicep femoris during the front squat.

To our knowledge, this is the first study to investigate peak and mean muscle activity and co-activation in those with and without hip flexor tightness during the front squat. Mills et al. (21) found significantly greater GM:BF co-activation ratio in female soccer players without hip flexor tightness during the descending phase of an overhead air squat. However, Mill and his colleagues contributed the difference in GM:BF co-activation due to significantly greater peak muscle activation of the gluteus maximus, whereas in the current study there were not significant differences in peak or mean GM during the front squat. Additionally, the current study found that females with tight hip flexors displayed significantly greater BF activity, whereas Mills et al. (21) did not find significant differences in the BF. This may be attributed to the etiology contributing to hip flexor tightness in Mill et al. (21) subjects versus the participants in the current study.

Possible causes of muscular imbalances include improper habitual patterns, chronic repetition of a movement, and altered movement due to previous injury (7-8, 15). Mills et al. (21) used female soccer players who were thought to develop hip flexor tightness through the repetitive hip flexion that is required in the sport. A plausible explanation for the decreased GM activity in the tight hip flexor group of the Mills et al. (21) study is that chronic hip flexion activity with shortened hip flexors contributed to the GM becoming underactive. While the current study used similar criteria for determining hip flexor tightness, it is unlikely that the population of the current study was exposed to the same amount of

Table 1. Normalized Peak Muscle Activity during 75% 1RM of the Front Squat

Variable	Non-Tight Hip flexors (*N* = 9; height: 163.27 ± 6.72 cm; body mass: 69.2 ± 6.46 kg; 1RM: 63.63 ± 12.41 kg)		Tight Hip Flexors (*N* = 7; height: 163.87 ± 7.46 cm; body mass: 68.78 ± 13.33 kg; 1RM: 79.2 ± 18.94 kg)						
	M	**SD**	**M**	**SD**	***t***	***p***	**Mean Difference**	**95% CI**	**Hedges' *g***
DSC RF	0.50	0.15	0.62	0.15	1.28	0.22	0.12	[-0.33, 0.08]	0.61
DSC BF	0.23	0.17	0.54	0.12	4.01	.001*	0.30	[-0.47, -0.14]	1.91
DSC ST	0.55	0.30	0.58	0.14	0.32	0.77	0.03	[-0.30, 0.23]	0.14
DSC GM	0.43	0.17	0.35	0.16	.830	0.42	0.07	[-0.11, 0.26]	0.40
ASC RF	0.59	0.23	0.86	0.12	2.86	0.01	0.28	[-0.48, 0.07]	1.36
ASC BF	0.45	0.28	0.74	0.21	2.27	0.040	0.28	[-0.55, -0.02]	1.08
ASC ST	0.56	0.16	0.63	0.27	0.60	0.32	0.06	[-0.29, 0.16]	0.29
ASC GM	0.81	0.14	0.69	0.22	1.27	0.23	0.11	[-0.07, 0.31]	0.60

**denotes a significant difference between individuals with and without hip flexor tightness; p < .002. DSC descending, ASC ascending, RF rectus femoris, BF biceps femoris, ST semitendinosus, GM gluteus maximus.*

Table 2. Normalized Mean Muscle Activity during 75% 1RM of the Front Squat

Variable	Non-Tight Hip flexors (*N* = 9; height: 163.27 ± 6.72 cm; body mass: 69.2 ± 6.46 kg; 1RM: 63.63 ± 12.41 kg)		Tight Hip Flexors (*N* = 7; height: 163.87 ± 7.46 cm; body mass: 68.78 ± 13.33 kg; 1RM: 79.2 ± 18.94 kg)						
	M	**SD**	**M**	**SD**	***t***	***p***	**Mean Difference**	**95% CI**	**Hedges' *g***
DSC RF	0.26	0.10	0.36	0.22	1.10	0.25	0.10	[-0.28, 0.78]	0.58
DSC BF	0.23	0.19	0.31	0.09	1.03	0.32	0.08	[-0.25, 0.09]	0.49
DSC ST	0.32	0.19	0.31	0.07	0.194	0.85	0.01	[-0.14, 0.17]	0.09
DSC GM	0.20	0.08	0.17	0.06	0.83	0.44	0.03	[-0.04, 0.11]	0.38
ASC RF	0.39	0.15	0.55	0.15	1.92	0.07	0.15	[-0.32, 0.02]	0.91
ASC BF	0.30	0.17	0.50	0.18	2.24	0.04	0.20	[-0.39, -0.01]	1.07
ASC ST	0.39	0.18	0.48	0.14	1.01	0.32	0.09	[-0.27, 0.10]	0.49
ASC GM	0.56	0.20	0.48	0.10	1.12	0.33	0.08	[-0.09, 0.26]	0.49

p < .002. DSC descending, ASC ascending, RF rectus femoris, BF biceps femoris, ST semitendinosus, GM gluteus maximus.

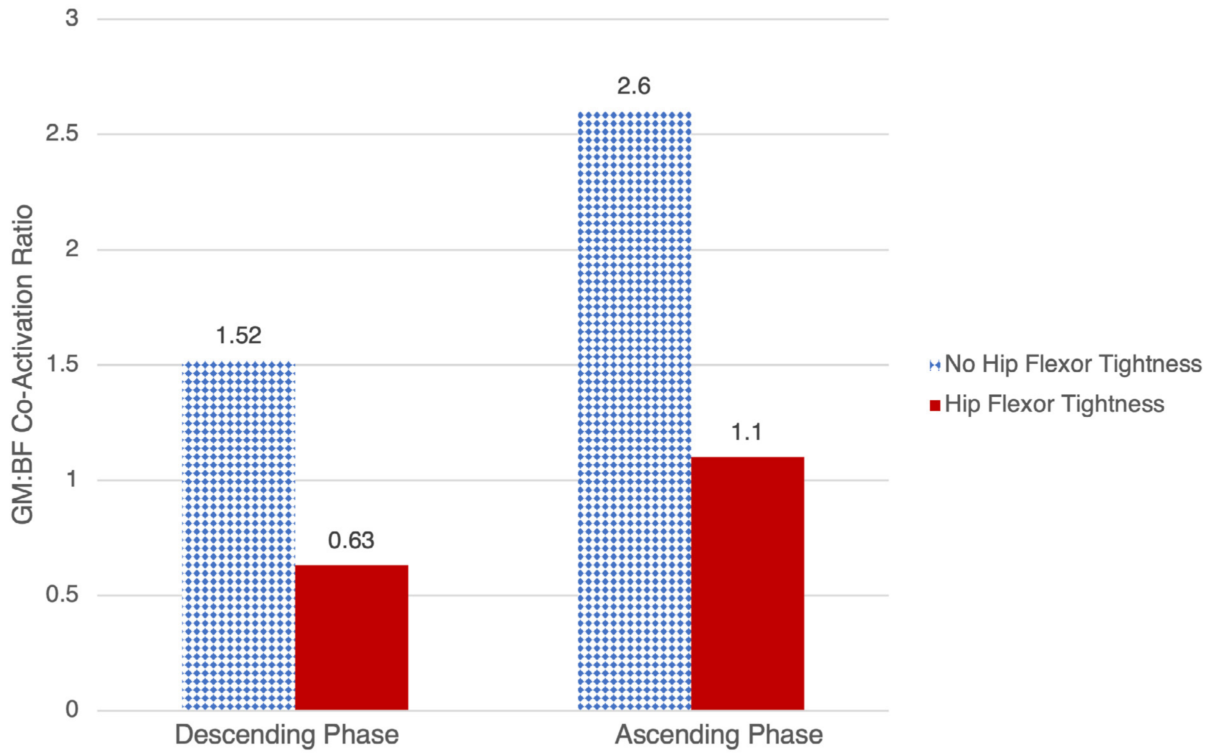

Figure 1. GM:BF Co-Activation Ratio during the Descending and Ascending Phases of 75% 1RM of the Front Squat.
Note. GM gluteus maximus, BF biceps femoris.

repetitive hip flexion as the population used by Mills et al. (21). Therefore, the lack of congruity in the GM findings between the current study and Mills et al. (21) may be explained by overuse of hip flexors that lead to hip flexor tightness.

While the current study did not demonstrate differences in GM activity between groups, the present study did find that females with tight hip flexors displayed significantly higher peak BF activity during the descending of the front squat. An external load of 75% 1RM for the front squat may have caused for optimal GM activation during hip extension in both groups, however the results of the current study suggest that females with overactive hip flexors required more recruitment of the synergist (BF). Thus, a higher external load during hip extension may cause greater reliance on synergist muscle activity during the descending phase of hip extension in those who experience hip flexor tightness. Muscle imbalances, such as synergistic dominance, can potentially result in the change in neuromuscular control, structural alignment, and movement patterns (7).

Synergistic dominance is a neuromuscular phenomenon in which a synergist muscle becomes overactive to compensate for a weak or inhibited prime mover (7-8). When tight hip flexors become overactive, there may be greater reliance on the synergist, hamstrings, to assist the GM in moving the body through hip extension (7-8; 16). Similar results were seen in other studies who investigated the effect of hip flexor tightness on lower extremity muscle activity during functional exercises (1, 27). Van Gelder and associates (27) found that individuals with hip flexor tightness consistently displayed greater time to peak in the BF compared to the GM and gluteus medias during the kettlebell swing. Another study by Aali et al. (1) found lower muscle activity GM:BF co-activation during the stance phase of gait in individuals with hip flexor tightness compared to their healthy counterparts. The combined results of the studies discussed support the notion that tight hip flexors can cause altered reciprocal inhibition that can lead to greater reliance of the BF during functional movements. To restore optimal function and appropriate balance between of a force couple it is recommended to stretch and lengthen the tight and overactive muscle (2, 7).

Strength and conditioning professionals should consider implementing hip flexor mobility exercises in their resistance training programs that involve the front squat to prevent over activation of the BF. Addressing and/or establishing proper hip mobility in female athletes may allow for optimal recruitment of lower extremity muscles during the front squat. This may help prevent synergistic dominance of the hamstrings, which has been shown to be related to increase the risk of hamstring injury during athletic performance and movements (3, 8, 24, 28). The observed overactivation of the biceps femoris during the front squat highlights the need for targeted interventions to optimize muscle recruitment and prevent potential imbalances or injuries.

The main limitation of this study was its exploratory nature (low sample size) and unequal groups (control group *n* = 9, experimental group *n* = 7). Thus, making the likelihood of a Type II error high. Another limitation to this study was the calculation of the GM:H ratio only considered the BF (21), which may not fully represent the function of the hamstring muscle group during hip extension. In addition, lumbopelvic movement was not controlled for during the modified Thomas Test as recommended by Vigotsky (30) and future investigations that replicate this study should be sure to control for lumbopelvic movement. Lastly, even though there are a multitude of articles published using EMG signals during resistance training lifts, there has been existing debate regarding the efficiency and interpretation of EMG in sport and caution should be used during analysis of EMG signals (31). Further investigations are required on the effect of hip flexor tightness on muscle activity. Future research may want to consider examining muscle activity under different external loads and athletic movements. Future studies should also investigate the relationship between hip flexor tightness and hamstring injury, as well as the effect of hip flexor tightness stretching programs on muscle activity.

CONCLUSION AND PRACTICAL APPLICATIONS

The results from the present study suggest that peak BF to be overactive in resistance trained females with hip flexor tightness during the front squat. This indicates that muscle activity may be more heavily affected under a higher load and individuals who squat at 75% 1RM should be aware of hip mobility to prevent over activation of the hamstring. Fitness professionals should consider providing a hip flexor stretching intervention to prevent over activation of the BF when selecting the front squat as a resistance training exercise. Providing a hip flexor stretching program to individuals who have tight hip flexors may decrease synergistic dominance of the biceps femoris.

REFERENCES

1. Aali, S, Letafatkar, A, Ebrahimi, I, Barati, AH, Hadadnejad, M. Does iliopsoas tightness affects synergistic muscle activity in hip extension during stance phase of gait?. International Journal of Medical Research & Health Sciences 6: 118-122, 2017.
2. Arboleda, BM, Frederick, AL. Considerations for maintenance of postural alignment for voice production. Journal of Voice 22: 90-99, 2008.
3. Aslan, HI, Buddhadev, HH, Suprak, DN, San Juan, JG. Acute effects of two hip flexor stretching techniques on knee joint position sense and balance. International Journal of Sports Physical Therapy 13: 846–859, 2018.
4. Buckthorpe, M, Stride, M, Villa, F. Assessing and treating gluteus maximus weakness - a clinical commentary. International Journal of Sports Physical Therapy 14: 655–669, 2019.
5. Burden, A. How should we normalize electromyograms obtained from healthy participants? What we have learned from over 25 years of research. Journal of Electromyography and Kinesiology 20: 1023–1035, 2010.
6. Clapis, PA, Davis. SM, Davis, RO. Reliability of inclinometer and goniometric measurements of hip extension flexibility using the modified Thomas Test. Physiotherapy Theory and Practice 24: 135-141, 2008.
7. Clark, MA, Lucett, SC, McGill, E, Montel, I, Sutton, B. National Academy of Sports Medicine Essentials of Personal Fitness Training (6th edition). Burlington, MA: Jones & Bartlett Learning, 2018, pp. 65-66, 94-107, 197-227.
8. Clark, M, Sutton, BG, Lucett, S. NASM Essentials of Corrective Exercise Training (1st edition). Burlington, MA: Jones & Bartlett Learning, 2014, pp. 167-172.
9. Contreras, BM, Cronin, JB, Schoenfeld, BJ, Nates RJ, Sonmez, GT. Are all hip extension exercises created equal?. Strength & Conditioning Journal, 35: 17-22, 2013.
10. Delgado, J, Drinkwater, EJ, Banyard, HG, Haff, GG, Nosaka, K. Comparison between back squat, Romanian deadlift, and barbell hip thrust for leg and hip muscle activities during hip extension. The Journal of Strength & Conditioning Research 33: 2595-2601, 2019.
11. Deniz, E, Ulas, YH. Evaluation of Muscle Activities During Different Squat Variations Using Electromyography Signals. International Conference on Theory and Application of Soft Computing, Computing with Words and Perceptions. Springer: Cham, 2019. pp. 859-865.
12. Ferber, R, Kendall, KD, McElroy, L. Normative and critical criteria for iliotibial band and iliopsoas muscle flexibility. Journal of Athletic Training, 45: 344-348, 2010
13. Haff GG, Triplett NT. Essentials of Strength and Conditioning. Champaign, IL: Human Kinetics, 2016. p. 442, 453.

14. Halaki, M, Ginn, K (2012). Normalization of EMG signals: To normalize or not to normalize and what to normalize to. Computational Intelligence in Electromyography Analysis – A Perspective on Current Applications and Future Challenges 10: 175–194, 2012.
15. Janda, V, Frank, C, Liebenson, C, Leibenson, C. Evaluation of muscular imbalance. Rehabilitation of the Spine: A Practitioner's Manual. Philadelphia, PA: Lippincott Williams & Wilkins, 1996, p. 205.
16. Kisner, C, Colby, LA, Borstad, J. Therapeutic Exercise: Foundations and Techniques. Philadelphia, PA: F.A. Davis Company, 2017, p. 774.
17. Korak, JA, Paquette, MR, Fuller, DK, Caputo, JL, Coons, JM. Muscle activation patterns of lower-body musculature among 3 traditional lower-body exercises in trained women. The Journal of Strength & Conditioning Research 32: 2770-2775, 2018.
18. McCurdy, K, Walker, J, Yuen, D. Gluteus maximus and hamstring activation during selected weight-bearing resistance exercises. The Journal of Strength & Conditioning Research 32: 594-601, 2018.
19. Mehls, K, Grubbs, B, Jin, Y, Coons, J. Electromyography comparison of sex differences during the back squat. Journal of Strength and Conditioning Research 36: 310-313, 2022.
20. Mehls, K, Grubbs, B, Stevens, S, Martinez, S, Jin, Y, Coons, J. Correcting movement syndromes: the role of training load and its effects on muscle. Sports Sciences for Health 21: 979-987, 2021.
21. Mills, M, Frank, B, Goto, S, et al. Effect of restricted hip flexor muscle length on hip extensor muscle activity and lower extremity biomechanics in college-aged female soccer players. International Journal of Sports Physical Therapy 10: 946–954, 2021.
22. Okkonen, O, Häkkinen, K. Biomechanical comparison between sprint start, sled pulling, and selected squat-type exercises. The Journal of Strength & Conditioning Research, 27: 2662-2673, 2013.
23. Peeler, J, Anderson, JE. Reliability of the Thomas test for assessing range of motion about the hip. Physical Therapy in Sport 8: 14-21, 2007.
24. Sahrmann, SA. Diagnosis and Treatment of Movement Impairment Syndromes. (1st Edition). St. Lois MO: Mosby, 2002, p. 162, 184-186.
25. SENIAM group. The SENIAM Project. Available at: http://www.seniam. org/.
26. Simenz, CJ, Garceau, LR, Lutsch, BN, Suchomel, TJ, Ebben, WP. Electromyographical analysis of lower extremity muscle activation during variations of the loaded step-up exercise. Journal of Strength and Conditioning Research, 26:, 3398–3405, 2012.
27. Van Gelder, LH, Hoogenboom, BJ, Alonzo, B, Briggs, D, Hatzel, B. EMG Analysis and Sagittal Plane Kinematics of the Two-Handed and Single-Handed Kettlebell Swing: A Descriptive Study. International Journal of Sports Physical Therapy 10: 811–826, 2015.
28. Wagner, T, Behnia, N, Ancheta, WK, Shen, R, Farrokhi, S, Powers, CM. Strengthening and neuromuscular reeducation of the gluteus maximus in a triathlete with exercise-associated cramping of the hamstrings. The Journal of Orthopaedic and Sports Physical Therapy 40: 112–119, 2010.
29. Yavuz, HU, Erdag, D. Kinematic and Electromyographic Activity Changes during Back Squat with Submaximal and Maximal Loading. Applied Bionics and Biomechanics, 2017.
30. Vigotsky, A. D., Lehman, G. J., Beardsley, C., Contreras, B., Chung, B., & Feser, E. H. (2016). The modified Thomas test is not a valid measure of hip extension unless pelvic tilt is controlled. PeerJ, 4, e2325.
31. Vigotsky, A. D., Halperin, I., Lehman, G. J., Trajano, G. S., & Vieira, T. M. (2018). Interpreting signal amplitudes in surface electromyography studies in sport and rehabilitation sciences. Frontiers in physiology, 985.