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Technical Note

The Influence of Normalization Technique on Between-Muscle Activation during a Back-Squat

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ABSTRACT

International Journal of Exercise Science 13(1): 1098-1107, 2020. Currently, no gold standard electromyography (EMG) normalizing technique exists when conducting between-muscle comparisons of muscle activity during isotonic resistance training exercises. The aim of this study was to assess if between-muscle activation during the back-squat differed among electromyography (EMG) normalization techniques when normalizing to: (1) 1 repetition maximum (1RM), (2) maximal voluntary isometric contraction (MVIC), and (3) the first of a set of three repetitions (Rep1%) in trained female lifters. Thirteen participants completed a back-squat 1RM, MVIC of the rectus-femoris (RF) and gluteus-maximus (GM), and three repetitions of the back-squat at 80% 1RM. For the 1RM and MVIC normalization techniques, the average of the peak RMS signal of both muscles during the three submaximal reps were normalized to the peak 1RM and MVIC signals. The Rep1% averaged the peak RMS signals of both muscles during the 2nd and 3rd submaximal repetitions normalized to the peak signal during the 1st repetition. The RF-GM between-muscle EMG (ΔEMG) differed among normalization techniques ($p < 0.001$, $\eta_p^2 = 0.48$). *Post-hoc* pairwise comparisons indicated MVIC normalization elicited different ΔEMG with large effects compared to both 1RM ($p = 0.037$; $d = 1.2$) and Rep1% ($p = 0.004$; $d = 1.9$) techniques, but the 1RM and Rep1% did not produce different ΔEMG ($p = 0.27$; $d = 0.8$). Our findings suggest EMG normalization technique influences the magnitude and direction of between-muscle activation during common lifting exercises, and we recommend normalizing isotonic movements to dynamic normalization methods such as a 1RM or Rep1%.

KEY WORDS: Electromyography, methodology, signal processing, lower extremity, training, exercise

INTRODUCTION

Electromyography (EMG) is the preferred tool to measure muscle activity during isotonic movements. Understanding how different muscles activate among resistance exercises are important to obtain specific desired training outcomes, specifically for scientists, clinicians, and sport science practitioners to better understand between-muscle involvement during different rehabilitation, sports performance, and activities of daily living tasks (19). When activity is compared among muscles for a specific movement, between studies and/or subjects, and across multiple testing days, EMG data must be normalized to reference data to account for electrode position differences, subcutaneous adipose tissue (i.e., signal impedance), and other signal interference factors (20). The SENIAM project has suggested normalizing data to a single-joint maximal voluntary contraction (MVC), though it was not specified to whether dynamic or isometric in nature (20, 28). Normalization of muscle activity, relative to single-joint maximal voluntary isometric contraction (MVIC) signal, is one of the most common procedures for normalizing EMG signals (26, 29). Another uses a single joint maximal isokinetic (i.e., fixed angular velocity) voluntary contraction either eccentrically or concentrically (10, 16, 25). These normalization techniques can be time consuming, require costly and specialized equipment (e.g., isokinetic dynamometer), and the single-joint movements can be unfamiliar to certain populations.

Although the single-joint MVC techniques are the most prevalent in the literature, other techniques have been used. These methods include normalizing muscle activity to the peak value of a maximal or submaximal effort of the same task (9, 25); mean value of the dynamic task (4); peak value of the dynamic task (30); peak value during several repetitions of an exercise (27); averaging peak values during the first repetition of a series of repetitions (Rep1%) for a resistance exercise (15, 17); and peak value during a 1-repetition maximum (1RM) of a resistance training exercise (18, 23). Ball and Scurr have suggested that EMG normalization should include normalization tasks that are similar to the movement under investigation, and ones that are familiar among testing participants (2). Currently, no studies have compared the use of different EMG normalization techniques for *between-muscle* comparisons when assessing muscle involvement in specific training exercises such as the squat. Therefore, the choice of which EMG normalization method to use when comparing activity between muscles within one exercise can be difficult.

The purpose of this study was to assess if different EMG normalization techniques (1RM, MVIC, Rep1%) alter the difference in muscle activity between rectus femoris (RF) and gluteus maximus (GM) during a back-squat exercise in female lifters. These three techniques were chosen since the Rep1% and MVIC techniques are most commonly selected during isotonic multi-joint resistance training movements (i.e. back-squat) (15, 17, 26, 29), while normalizing to a 1RM is a relatively new method not previously compared with other techniques (18, 23). It was hypothesized that the change in EMG (ΔEMG) between RF and GM would not differ between the 1RM and Rep1% technique, since the 1RM and Rep1% techniques are similar dynamic tasks. However, we hypothesized that the MVIC technique would produce different ΔEMG between RF and GM when compared to both the dynamic 1RM and Rep1%

METHODS

Participants

A power analysis conducted using G*Power 3.1.9.2 (Universitat Kiel, Germany) with an effect size set at 0.5, an alpha level of 0.05, and power of 0.80 indicated a sample size of nine participants was needed. Moderately trained women (n = 13) were included in the study (22.8 ± 3.1 years; 166.4 ± 4.2 cm; 73.4 ± 14.0 kg). Participants were required to have a minimum of one-year resistance training experience and had participated in resistance training for 6-months prior to beginning the study; however, some participants had multiple years of training experience. Participants 1RM for the back-squat ranged from 55.0 to 91.4 kg, which averaged to 104% of their body mass. All potential participants were excluded if they had a current musculoskeletal injury or were rehabilitating an existing injury. All participants provided verbal and written consent to take part in the study protocol approved by the Institutional Review Board. This study adhered to the ethical issues relating to scientific discovery in exercise science set by Navalta et al., (21).

Protocol

Participants were required to attend two testing sessions separated by at least 48-hours. Participants were asked to refrain from lower body resistance training 48-hours prior to the first testing session and during study participation. Briefly, session one included completion of a 1RM back-squat with no muscle activation recorded, while session two involved repeating the 1RM back-squat with the same load from session one, MVICs of the RF and GM muscles, and three submaximal repetitions with muscle activity measured throughout.

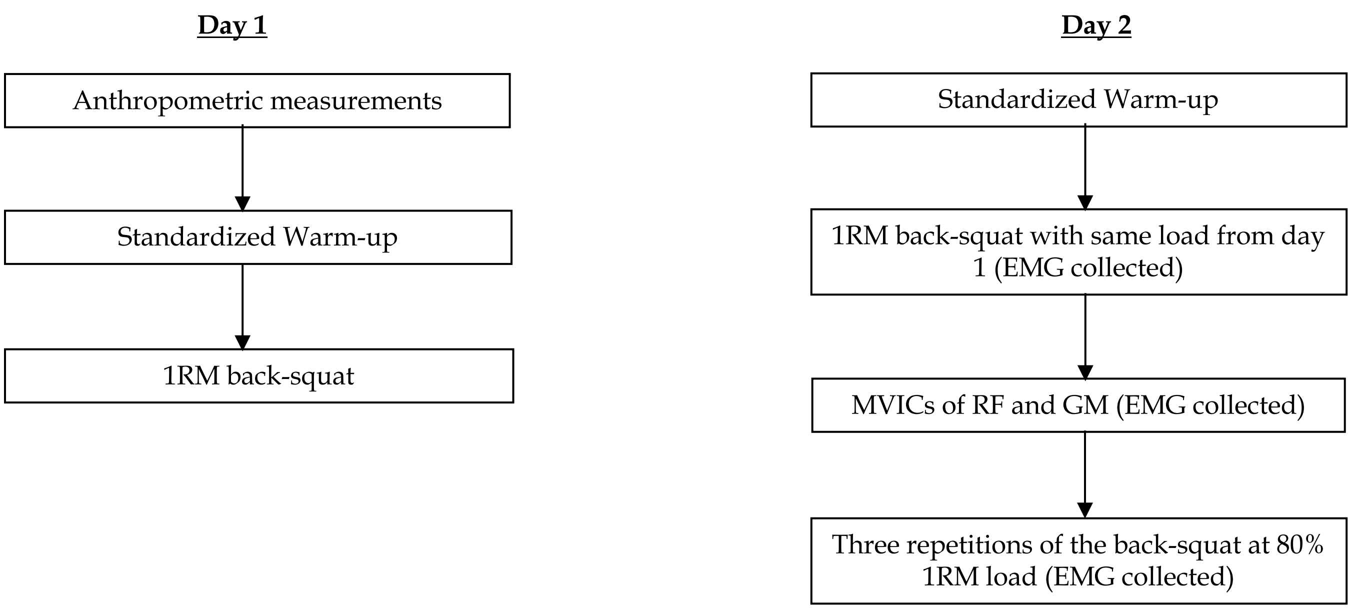

Figure 1. Participant flow chart for the testing protocol.

More thoroughly, Session one included anthropometric measurements and completion of a 1RM for the Smith machine back-squat. The 1RM was performed using a Pro Elite Systems® machine (Salt Lake City, UT). Prior to testing, participants completed a 5-minute treadmill walking warm-up at a self-selected pace, followed by squatting with a load that could be performed for 15 repetitions. A 1RM back-squat was then assessed following the guidelines set forth by the American College of Sports Medicine to determine the appropriate weight for session two testing (8). A bungee cord was placed at a depth where participant's thighs were parallel with the floor to ensure consistent form (18). For a repetition to be successful, participants had to touch the cord with their buttocks at the bottom of the squat (18). This 1RM was obtained during session one to avoid fatigue during the repeated 1RM that occurred during session two. No muscle activation was measured during session one (Figure 1).

Session two consisted of a 1RM with the same weight used during session one, MVIC measurements, and three repetitions of the back-squat exercise at 80% 1RM load. During all movements, muscle activity of RF and GM was measured using a wireless EMG system (2000 Hz, Trigno, Delsys, Natick, MA). Prior to testing, skin was swabbed with alcohol to remove excess skin oil, redux exfoliation paste was applied, and hair was shaved to minimize signal impedance. The wireless bipolar electrodes were then placed on the skin using double-sided tape over the RF and GM of the dominant limb (i.e., leg used to kick a soccer ball) using SENIAM guidelines (20). Participants were instructed to contract the muscles isometrically to endure appropriate electrode placement during the squats. Adhesive stretch tape was used over each electrode in order to minimize movement during testing.

Utilizing the same warm-up protocol, participants then completed a 1RM back-squat using the predetermined weight from session one. Following a 10-minute rest period, participants completed one MVIC trial for knee extension and hip extension according to procedures established by Garden and Bodenheimer (11). For the MVIC testing, participants were first shown how to successfully complete the procedure. Participants were also given one unrecorded practice attempt for each muscle. The MVIC of the knee extensors was performed in the seated position on a training table, hands secured to keep the buttocks against the seat, knee and hip angles positioned at approximately 90°. When instructed, participants pushed against an immovable resistance for 3-seconds as fast and has hard as possible; participants were given verbal encouragement by two investigators. The MVIC of the hip extensors was performed in the prone position on a standard athletic training table, with the femur parallel with the floor, and knee bent at 90°. Participants were instructed to maximally push their foot directly upwards towards the ceiling, isolating the GM muscle for 3-seconds against an immovable resistance as fast and with as much force as possible.

Following a 10-minute rest, participants then performed three repetitions of the back-squat exercise at 80% 1RM load. Load was selected due to being a standard hypertrophy style-training regimen (13). A high bar placement was used across the posterior deltoids at the middle of the trapezius with feet shoulder width, toes facing forward, while descending until the anterior aspect of the thighs were parallel with the floor (13). Repetitions were completed on pace with a metronome with a 2-second descending movement and a 1-second ascending movement. As stated previously, to ensure adequate squat depth, a bungee cord was positioned horizontally under the participants where their buttocks would touch the cord at a height corresponding to their thigh being parallel with the floor.

All raw surface EMG data during the entire squat movement were band-pass filtered with high and low-pass cut-off frequencies of 20 and 450 Hz, respectively (29). The signals were then full-wave rectified and smoothed using a root mean square (RMS) filter with a moving window length of 125 ms, with a window overlap of 62.5 ms (29).

For the 1RM and MVIC normalization techniques, the average peak of the processed RMS signals using a three frame detection window for RF and GM of the three submaximal squat repetitions were normalized to the peak processed RMS value of each muscle during 1RM and MVIC of each muscle (Table 1). For the Rep1% normalization technique, average peak of the processed RMS signals for RF and GM from the second and third repetitions were normalized to the peak processed RMS value of each muscle during the first repetition (Table 1). In order to make between muscle comparisons, the difference in the normalized EMG signal between RF and GM (ΔEMG) from each normalization method was used in the statistical analyses by subtracting the GM normalized EMG signal from the RF normalized signal. A positive ΔEMG signified greater RF activity while a negative ΔEMG signified greater GM activity during the squat exercise.

Table 1. Normalization techniques for the rectus femoris and gluteus maximus muscles during the 1RM, MVIC, and Rep1% methods (n = 13).

Normalization Method	Numerator	Denominator
1RM	average peak of 3 submaximal reps	peak muscle activity during 1RM
MVIC	average peak of 3 submaximal reps	peak muscle activity during MVIC
Rep1%	average peak of reps 2 and 3	peak muscle activity of rep 1

Statistical Analysis

A one-way analysis of variance with normalization technique as the within-subject factor (1RM, MVIC, Rep1%) was used to compare the effects of normalization method on ΔEMG between RF and GM during the squat ($\alpha \leq 0.05$). A Sidak procedure was used *post-hoc*, pairwise comparisons and Cohen's d effect sizes were computed to assess magnitudes of mean differences between techniques with Hopkins' interpretation (small: $d < 0.8$; moderate: $0.8 \leq d < 1.2$; large: $d \geq 1.2$) (14). All data met parametric assumptions required to complete the analysis of variance.

RESULTS

Average 1RM squat for the participants was 104% of their body mass. Normalized peak RMS EMG signal for both muscles using the three normalization techniques are shown in Table 2.

Table 2. Descriptive statistics of rectus femoris and gluteus maximus muscle activation among three normalization methods viewed as a percentage (n = 13).

Muscle	1RM	MVIC	Rep1%
Rectus Femoris	85.0 ± 11.4	132.8 ± 51.1	101.1 ± 13.2
Gluteus Maximus	79.8 ± 30.2	77.4 ± 42.8	118.2 ± 25.2

Note. 1 RM, MVIC, Rep1% are represented as mean standard deviations.

The analysis of variance indicated ΔEMG between the RF and GM differed among the three normalization techniques ($p < 0.001$; Figure 2). *Post-hoc* tests found the MVIC normalization technique elicited different ΔEMG compared to the 1RM ($p = 0.037$; $d = 1.2$) and Rep1% ($p = 0.004$; $d = 1.9$) normalization techniques but ΔEMG was not different between the 1RM and Rep1% normalization techniques ($p = 0.27$; $d = 0.8$).

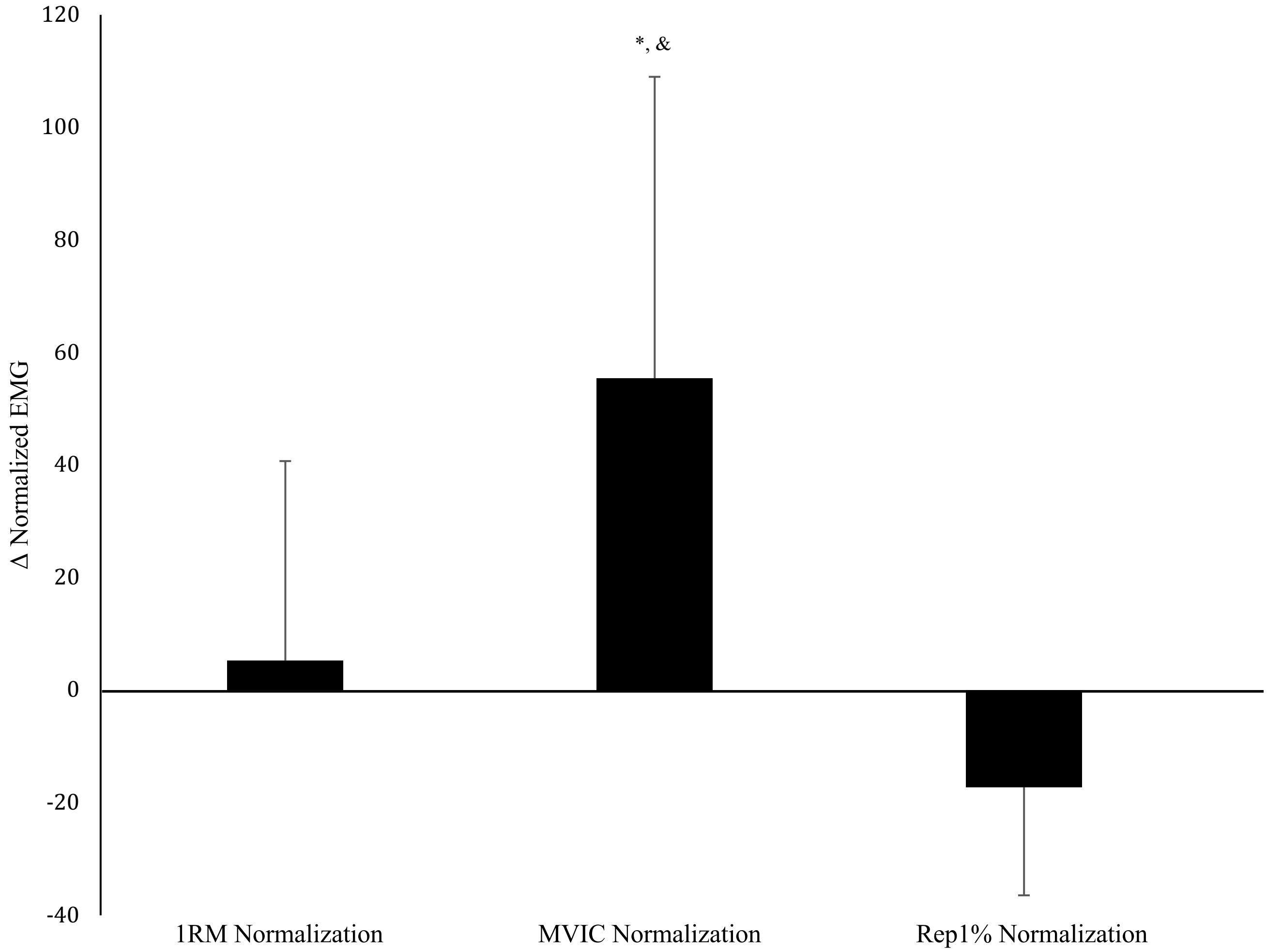

Figure 2. Muscle activity differences between rectus femoris (RF) and gluteus maximus (GM) (ΔEMG) among the three different normalization methods. *: different than 1RM; &: different than Rep1% ($p < .05$). Positive (ΔEMG): more RF muscle activity vs GM.

DISCUSSION

The purpose of this study was to assess if different EMG normalization procedures alter ΔEMG between RF and GM during the back-squat. To our knowledge, the current study appears to be the first to assess normalization technique on between-muscle comparisons. Between-muscle EMG comparisons are useful to scientists, clinicians, and sport science practitioners to better understand between-muscle involvement during different rehabilitation, sports performance, and activities of daily living tasks (19). Our findings support our hypothesis as the MVIC normalization technique elicited different ΔEMG compared to the 1RM and Rep1% normalization techniques while ΔEMG was similar between the 1RM and Rep1% normalization techniques (Figure 2). Since the 1RM and Rep1% normalization methods were performed during the same movement task included in experimental testing, it was expected that the RF and GM ΔEMG would not differ between these normalization techniques. The findings from this study provide important methodological insight regarding normalization techniques for between-muscle EMG comparisons.

One explanations for the statistical outcome could be due to the fact that RF is a bi-articular muscle acting as both a knee extensor and hip flexor and as a result, RF activity during the MVIC depends on both knee and hip position. In the current RF MVIC testing protocol, and other study protocols for knee extensor testing, participants were seated (1, 6, 12). In this position, a shortened RF due to hip joint flexion may lead to greater recruitment of other knee extensors and reduced RF involvement and/or activity. Indeed, force output during single-joint isometric contractions is dependent on muscle length (9, 22, 24). During the back-squat, concurrent movement of the knee and hip joints (i.e., flexion at both joints on way down and extension at both joints on way up) help maintain relative length of RF in order to maintain force output and ultimately, muscle activity. The reduced RF activity during the MVIC and the relatively greater RF activity during the back-squat leads to higher RF activity percentage of MVIC during testing. Contrarily, since the GM is a uni-articular muscle of the hip, knee joint position during MVIC testing does not influence GM activity. Therefore, an increased normalized RF compared to GM activity during the back-squat contributes to greater ΔEMG between RF and GM when using the MVIC method. Lastly, while both muscles are prime mover muscles during the back-squat exercise, they perform different joint actions. For example, the GM performs hip extension while the RF performs both knee extension and hip flexion (20).

Balshaw and Hunter (3) found that normalizing the vastus lateralis (VL) and biceps femoris EMG to a dynamic method during the back-squat was superior to MVIC due to reduced inter-participant variability, absolute reliability and sensitivity; though no between-muscle ΔEMG were compared. EMG normalization to a 1RM may be the most effective when involving resistance training movements for a multitude of reasons: First, the 1RM, in theory, is a MVC; second, this normalization technique uses the exact movement being studied (i.e. three submaximal repetitions at a submax 1RM load); and third, the 1RM is more likely to be a familiar movement to trained participants compared to a single-joint MVIC. Our current findings indicate that it is highly important to be selective when choosing a normalization method during isotonic resistance exercises since between-muscle EMG comparisons are dependent on normalization technique.

Although not statistically different ($p = 0.27$), the ΔEMG for the 1RM technique elicited a positive value (i.e., greater RF vs GM activity) while the Rep1% technique produced a negative value (i.e., greater GM vs RF activity) during the back-squat (Figure 2). One possible explanation for lesser GM compared to RF activation outcome using the 1RM normalization technique might include greater involvement of synergistic muscles (e.g., gluteus medius, gluteus minus, tensor fasciae latae, and external rotators) to stabilize the hip joint and pelvis in hip extension during the maximal effort 1RM. More synergistic muscle involvement during the 1RM could reduce the force production requirement of GM, lower its' activity, and explain the positive ΔEMG using the 1RM technique (Figure 2). Further, all four knee extensor muscles were likely all active to the same degree during the squat according to previous literature, even though only the RF was measured (12, 18,). For example, Gullet et al. (12) found muscle activation of the RF, VL, and vastus medialis (VM) ranged from 60-80% during front and back-squats at 70% 1RM load, while Korak et al. (18) discovered the same muscles ranged from 95-103% for the same lifts at 75% 1RM load. Lastly, Yavuz et al. (29) found VL and VM mean muscle activation differed by 1% during a 1RM back-squat. It is difficult to explain the ΔEMG direction difference between normalizing techniques without additional EMG data on synergist muscles, but future research should examine this postulation by including analyses of synergistic muscle activation patterns during maximal vs. submaximal lifts.

A potential limitation of this study was we the authors did not measure EMG reliability across multiple testing days. It is plausible that the EMG signal could have differed from day-to-day due to sensor placement variability, electrode movement, sweat, sensor "crosstalk", and hydration status (7). While Balshaw and Hunter (3) found normalizing muscle activation to a dynamic task elicits better absolute reliability and sensitivity across four days of testing compared to a MVIC, separate muscles were examined, and between-muscle activation comparisons were not measured. On the contrary, Colquhoun et al. (5) found that VL activity was reliable across three sessions of MVIC testing. Future studies should replicate the current methodology examining reliability across multiple days of testing, and examine synergistic muscles.

Findings from the current study indicate that ΔEMG of RF and GM during the back-squat are highly influenced by EMG normalization technique. However, significant and meaningful differences in ΔEMG were observed between the MVIC technique and both the 1RM and Rep1% techniques. We recommend that signal from a 1RM or maximal effort of a specific movement, or from the first repetition of a set should be used to normalize EMG signals when comparing muscle activity between muscles during a closed-kinetic chain resistance exercise. Future research should compare EMG normalization techniques for sports-specific movements (e.g., pitching, running, landing, cutting, swinging an implement), for different muscles, and for athletes of different experience levels. Future studies should also replicate the current methodology examining day-to-day EMG reliability.

REFERENCES

1. Alkner BA, Tesch PA, Berg HE. Quadriceps EMG/force relationship in knee extension and leg press. Med Sci Sports Exerc 32(2): 459, 2000.

2. Ball N, Scurr J. Electromyography normalization methods for high-velocity muscle actions: review and recommendations. J App Biomech 29(5): 600-608, 2013.

3. Balshaw TG, Hunter AM. Evaluation of electromyography normalisation methods for the back squat. J Electro Kinesio 22(2): 308-339, 2012.

4. Boyer KA, Nigg BM. Muscle activity in the leg is tuned in response to impact force characteristics. J Biomech 37(10): 1583–1588, 2004.

5. Colquhoun RJ, Tomko PM, Magrini MA, Muddle TW, Jenkins NDM. The influence of input excitation on the inter-and intra-day reliability of the motor unit firing rate versus recruitment threshold relationship. J Neurophysiology 120: 3131-3139, 2018.

6. Contreras B, Vigotsky AD, Schoenfeld BJ, Beardsley C, Cronin J. A comparison of gluteus maximus, biceps femoris, and vastus lateralis electromyography amplitude in the parallel, full, and front squat variations in resistance-trained females. J App Biomech 32(1): 16-22, 2016.

7. Criswell, E. Cram's introduction to surface electromyography. Sudbury, MA: Jones and Bartlett Publishers, 2011.

8. Dumke LD. *ACMS's Guidelines for Exercise Testing and Prescription*. 10th edition Philadelphia, PA: Williams & Wilkins; 2018: 101.

9. Ekstrom RA, Osborn RW, Goehner HM, Moen AC, Ommen BM, Mefferd MJ,... Kelsey SA. Electromyographic normalization procedures for determining exercise intensity of closed chain exercises for strengthening the quadriceps femoris muscles. J Strength Cond Res 26(3): 766-771, 2012.

10. Fernández-Pena E, Lucertini F, Ditroilo M. A maximal isokinetic pedalling exercise for EMG normalization in cycling. J Electro Kinesio 19(3): 162-170, 2009.

11. Garden FH, Bodenheimer C. Handbook of manual muscle testing. In: Cutter NC, Kevorkian GC, eds. New York, NY: McGraw-Hill, 1999: 121-154.

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

13. Haff GG, Triplett NT. Exercise technique for free weight and machine training. In: Essentials of strength and conditioning. Champaign, IL: Human Kinetics, 380-81, 2015.

14. Hopkins WG, Marshall SW, Batterham AM, Hanin J. Progressive statistics for studies in sports medicine and exercise science. Med Sci Sport Exercise 41: 3–13, 2009.

15. Kay D, Marino FE. Cannon J, St Clair Gibson A, Lambert MI, Noakes TD. Evidence for neuromuscular fatigue during high-intensity cycling in warm, humid conditions. Eur J Appl Physiol 84(1): 115–121, 2001.

16. Kellis E, Baltzopoulos V. The effects of normalization method on antagonistic activity patterns during eccentric and concentric isokinetic knee extension and flexion. J Electro Kinesio 6(4): 235-245, 1996.

17. Korak JA, Paquette MR, Brooks J, Fuller DK, Coons JM. Effect of rest-pause vs. traditional bench press training on muscle strength, electromyography, and lifting volume in randomized trial protocols. Eur J Appl Physiol 117(9): 1891-96, 2017.

18. Korak JA, Paquette MR, Fuller DK, Caputo JL, Coons JM. Muscle Activation Patterns of Lower Body Musculature Among Three Traditional Lower Body Exercises in Trained Women. J Strength Cond Res 32(10): 2770-2775, 2018.

19. McCurdy K, Walker J, Yuen D. Gluteus Maximus and Hamstring Actiavation During Selected Weight-Bearing Resistance Exercises. J Strength Cond Res 32(3): 594-601, 2017.

20. Merletti R, Wallinga W, Hermens HJ, Freriks B. Guidelines for reporting SEMG data. In:Hermens HJ, Freriks B, Merletti R, Stegeman D, Blok J, Rau G, Disselhorst-Klug C, Hägg G, editors. European recommendations for surface electromyography: results of the SENIAM project. Enschede: Roessingh Research and Development;103–105, 1999.

21. Navalta JW, Stone WJ, Lyons S. Ethical Issues Relating to Scientific Discovery in Exercise Science. Int J of Exercise Sci 12(1): 1-8, 2019.

22. Nazmi N, Abdul Rahman MA, Yamamoto SI, Ahmad SA, Zamzuri H, Mazlan SA. A review of classification techniques of EMG signals during isotonic and isometric contractions. Sensors 16(8): 1304, 2016.

23. Nijem R, Coburn J, Brown L, et al. Electromyographic and force plate analysis of the deadlift performed with and without chains. J Strength Cond Res (30): 1177-1182, 2016.

24. Rassier DE, MacIntosh BR, Herzog W. Length dependence of active force production in skeletal muscle. J App Biomech 86(5): 1445-1457, 1999.

25. Suydam SM, Manal K, Buchanan TS. The advantages of normalizing electromyography to ballistic rather than isometric or isokinetic tasks. J App Biomech 33(3): 189-196, 2017.

26. 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. American J Sports Med 24(4): 518-527, 1996.

27. Wright GA, Delong TH, Gehlsen G. 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.

28. Yang JF, Winter DA. Electromyographic amplitude normalization methods: improving their sensitivity as diagnostic tools in gait analysis. Archives Physical Med Rehab 65(9): 517–521, 1984.

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