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Review article

Gluteus Maximus Activation during Common Strength and Hypertrophy Exercises: A Systematic Review

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Abstract
The gluteus maximus (GMax) is one of the primary hip extensors. Several exercises have been performed by strength and conditioning practitioners aiming to increase GMax strength and size. This systematic review aimed to describe the GMax activation levels during strength exercises that incorporate hip extension and use of external load. A search of the current literature was performed using PubMed/Medline, SportDiscuss, Scopus, Google Scholar, and Science Direct electronic databases. Sixteen articles met the inclusion criteria and reported muscle activation levels as a percentage of a maximal voluntary isometric contraction (MVIC). The exercises classified as very high level of GMax activation (>60% MVIC) were step-up, lateral step-up, diagonal step-up, cross over step-up, hex bar deadlift, rotational barbell hip thrust, traditional barbell hip thrust, American barbell hip thrust, belt squat, split squat, in-line lunge, traditional lunge, pull barbell hip thrust, modified single-leg squat, conventional deadlift, and band hip thrust. We concluded that several exercises could induce very high levels of GMax activation. The step-up exercise and its variations present the highest levels of GMax activation followed by several loaded exercises and its variations, such as deadlifts, hip thrusts, lunges, and squats. The results of this systematic review may assist practitioners in selecting exercised for strengthening GMax.

Keywords: Skeletal muscle, gluteus maximus, electromyography, strength training.

Introduction

Hip extension is a fundamental movement in daily life and athletic activities. Previous research has proposed an increasing role of hip extensor musculature with heavier lower body exercises (e.g., squats, lunges, and deadlifts) and explosive sports actions (e.g., jumping, sprinting and change of direction) (Beardsley and Contreras, 2014). The primary muscles responsible for this movement are gluteus maximus (GMax), long head of biceps femoris, semimembranosus, semitendinosus, and the ischiocondylar portion of the adductor magnus (Broski et al., 2015; Neumann, 2010; Youdas et al., 2017). Despite the involvement of all these muscles, GMax has been identified as the primary muscle responsible for hip extension, specifically on loaded exercises that typically do not sufficiently activate the hamstrings in tasks involving simultaneous hip and knee extension, such as the squat and the leg press (Krause Neto et al., 2019, McCurdy et al., 2018; Williams et al., 2018; Sugisaki et al., 2014). There is a significant number of studies comparing GMax activation levels between several loaded and bodyweight exercises (Bishop et al., 2018; Boren et al., 2011; Macadam et al., 2015; Macadam and Feser, 2019; Selkowitz et al., 2016).

Electromyography (EMG) is a technique for measuring the electric potential field generated by the depolarization of the sarcolemma (Merletti and Parker, 2004). Despite limitations and common misinterpretations (Vigostky et al., 2015; 2016), under controlled conditions, the EMG signal comprises the summation of motor unit action potentials and provides an index of muscle activation (Enoka and Duchateau, 2015). Therefore, EMG has been widely used to compare the muscle activation between exercises, which can assist the strength and conditioning coach on selecting and systematically progressing exercise intensity (Vigostky et al., 2015, Macadam and Feser, 2019).

Previous studies have systematically reviewed the gluteal muscle activity, measured by EMG, in a variety of lower body exercises (Macadam et al., 2015; Macadam and Feser, 2019). The systematic review conducted by Macadam et al. (2015) showed that exercises with dynamic hip abduction and external rotation elicited high levels of GMax activation (ranging from 79% to 113% of a maximal voluntary isometric contraction [MVIC]). Recently, Macadam and Feser (2019) have found that it is still possible to achieve high levels of GMax activation (>60% of MVIC) by performing exercises with bodyweight as resistance. However, due to the inclusion/exclusion criteria chosen by the authors to answer their research questions, both studies eventually excluded more ecologically valid studies for strength and conditioning coaches that investigated exercises with higher intensity (external load) and neuromuscular demand. As external load may affect exercise mechanics and the resultant muscular activation (Bryanton et al., 2012; Da Silva et al., 2008; Riemann et al., 2012; Swinton et al., 2011), currently there is ambiguity on which exercises that incorporate hip extension and use of external load achieve the most significant Gmax activation.

Several factors, including relative external load, movement velocity, level of fatigue, the mechanical complexity of the exercise (open or closed kinetic chain, weight bearing or non-weight bearing), and the need for joint stabilization, may directly influence GMax activation. The purpose of this systematic review was to describe the

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GMax activation levels during dynamic exercises that incorporate hip extension and use of external load. To assist strength and conditioning coaches in selecting exercises for the GMax, we categorized the exercises as low level of activation (0 to 20% of MVIC), moderate level of activation (21 to 40% of MVIC), high level of activation (41 to 60% of MVIC), and very high level of activation (greater than 60% of MVIC) accordingly to the recommendations of Macadam and Feser (2019).

Methods

Literature research strategies

The preferred item declaration guide for systematic review and meta-analysis reports (PRISMA) was used to conduct this systematic review (Liberati et al., 2009).

On February 15th, 2019, a systematic review was conducted using the PubMed/Medline, SportDiscuss, Scopus, Google Scholar, and Science Direct electronic databases. The MeSH descriptors, along with the related terms and keywords, were used as follows: ((((resistance training OR resistance exercise OR training, resistance OR strength training OR training, strength OR weight-lifting strengthening program OR strengthening program, weight-lifting OR strengthening programs, weight-lifting OR weight lifting strengthening program OR weight-lifting strengthening programs OR weight-lifting exercise program OR exercise program, weight-lifting OR exercise programs, weight-lifting OR weight lifting exercise program OR weight-lifting exercise programs OR weight-bearing strengthening program OR strengthening program, weight-bearing OR strengthening programs, weight-bearing OR weight bearing strengthening program OR weight-bearing strengthening programs OR weight-bearing exercise program OR exercise program, weight-bearing OR exercise programs, weight-bearing OR weight bearing exercise program OR weight-bearing exercise programs OR isometric OR exercise OR rehab OR physical therapy OR load OR training))) AND ((muscle development OR development, muscle OR muscular development OR development, muscular OR myogenesis OR myofibrillogenesis OR muscle hypertrophy OR hypertrophy OR hypertrophies OR electromyography OR electromyographies OR surface electromyography OR electromyographies, surface OR electromyography, surface OR surface electromyographies OR electromyogram OR electromyograms OR muscle strength OR power output OR force OR strength OR muscular excitation OR excitation OR EMG OR muscle activation OR activation))) AND ((gluteus maximus OR gluteus OR hip extensor OR hip extensors)).

After reading the titles and abstracts, all eligible full text was assessed for methodological quality using the PEDro methodological quality scale. This scale is composed of eleven questions and scores proportional to the number of items. However, due to the inability to "blind" coaches and practitioners, we excluded three questions, setting the eight as the maximum score. Thus, studies with scores equal to or higher than five were considered of good methodological quality, excluding those with scores equal to or less than 4 (Krause Neto et al., 2019).

Inclusion and exclusion criteria

The inclusion criteria were: (a) original articles; (b) descriptive studies (in case of no raw description of the data, an e-mail was sent to the authors requesting the raw data); (c) studies with physically trained participants; (d) studies that measured surface EMG and reported muscle activation as a percentage of maximal voluntary isometric contraction (MVIC); (e) studies which analyzed the muscle activation of the GMax using strength exercises with external load and (f) English language. Studies with insufficient data, review articles, conference papers, student thesis, samples from metabolic patients, patients with musculoskeletal trauma and older people, poor presentation of data, unclear or vague descriptions of the protocols applied, and articles evaluating isometric, plyometrics, and calisthenics exercises were excluded.

Studies selection

Authors WKN, RA, and TAC independently performed the data analysis with two subsequent meetings to decide on the inclusion of eligible articles in the final text. After each article was read, the following information was extracted: (1) exercise performed, (2) EMG normalization procedure, (3) electrode placement, (4) external load used in the exercise, (5) main findings and (6) mean %MVIC values achieved in each exercise. If two or more studies evaluated the same exercises, the data were pooled as an average of the mean % MVIC of each exercise. Only the mean %MVIC data from each study was used here.

To classify the Gmax activation measured, we used the following levels: 0-20% MVIC, low muscle activation; 21-40% MVIC, moderate muscle activation; 41-60% MVIC, high muscle activation; >60% MVIC, very high muscle activation (Escamilla et al., 2010; Youdas et al., 2014, Cacchio et al., 2008). According to Macadam and Feser (p. 17, 2019), "*this classification scheme provides a means by which the practitioner can select exercises, that match the capabilities of their client/athlete thus targeting neuromuscular, endurance, or strength type training, and provides a means by which the GMax can be progressively overloaded in a systematic fashion*."

Results

Search results

A total of 1963 articles were identified in the initial survey. After the analysis of the titles/abstracts, 1853 articles were eliminated, leaving 110 articles selected for full-text examination. After two meetings and discussion of the data, 61 items were included and evaluated by the methodological quality scale and inclusion/exclusion criteria, of which 16 articles were eligible for this systematic review (Figure 1).

In total, 231 participants (90 women and 141 men) underwent 24 strength exercises variations. Table 1 describes the exercises investigated, methods of EMG normalization, testing load, and the main findings. Of these, ten studies investigated the back squat exercise and its variations [partial, parallel and full] (Aspe and Swinton, 2014; Contreras et al., 2015b; 2016a; Da Silva et al., 2017; Evans et al., 2019; Gomes et al., 2015; McCurdy et al., 2018; Williams et al., 2018; Yavuz et al., 2015; Yavuz and Erdag, 2017), five studies investigated the barbell hip thrust and its variations [American and traditional styles and different feet positions] (Andersen et al., 2018; Collazo Garcia et al., 2018; Contreras et al., 2015b; 2016b; Williams et al., 2018), three studies investigated the deadlift, and its variations [traditional and hex bar] (Andersen et al., 2018; Escamilla et al. 2002; McCurdy et al., 2018) and two studies investigated the front squat (Contreras et al., 2016a; Yavuz et al., 2015). Other studies investigated the overhead squat (Aspe and Swinton, 2014), split squat (Williams et al., 2018), modified single-leg squat (McCurdy et al., 2018), belt squat (Evans et al., 2019), lunges (Marchetti et al., 2018), and step-ups (Simenz et al., 2012). External loads were prescribed either by % of 1RM (varied from 40 to 100% of 1RM) or repetition maximum (varied from 3 to 12RM). The methods for normalizing EMG levels varied among the studies; the positions glute squeeze, standing glute squeeze, and prone with 90° flexion being the most common (Table 1). Interestingly, three studies evaluated the lower and upper GMax portions separately (Contreras et al., 2015b; Contreras et al., 2016a; Contreras et al., 2016b).

Although there was no time limit as an inclusion criterion, all the articles included in this review were published between the years of 2002 and 2019. After the methodological quality analysis, all included studies were classified as excellent (mean score 7).

Muscle activation levels

Table 2 describes the pooled average muscle activation levels and the minimum and maximum EMG values for each exercise. In general, the step-up exercise and its variations [lateral, diagonal, and cross-over] showed the highest GMax activation (average 125.09% MVIC, ranging from 104.19-169.22% MVIC).

In Table 3, it is possible to verify that 24 variations related to the ten main exercises included in this study were investigated. In this analysis, the classification of the exercises regarding the activation of GMax ranged from moderate to very high. Among all, the step-up exercise demonstrated the highest Gmax activation. However, possibly due to the wide variation of methods used for EMG normalization, at least 16 exercises variations presented similar maximum Gmax excitatory levels (step-up, lateral step-up, diagonal step-up, crossover step-up, hex bar deadlift, rotation barbell hip thrust, traditional barbell hip thrust, American barbell hip thrust, belt squat, split squat, in-line lunge, traditional lunge, pull barbell hip thrust, modified single-leg squat, band hip thrust and conventional deadlift [Figure 2]).

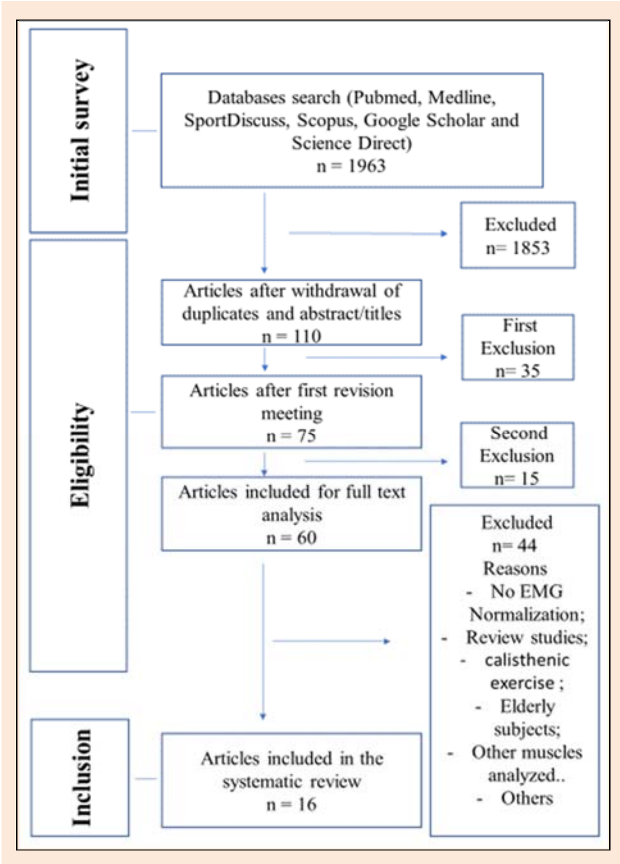

Figure 1. Search and screening procedure.

Table 1. Description of data extracted from each article about subtopics: exercises, electromyography signal normalization (EMG) method, electrode placement, testing load, and main findings.

References	Exercises	EMG normalization method	Electrode placement	Testing Load	Main Findings
Williams et al. 2018	Back Squat, Barbell Hip Thrust and Split Squat	Standing glute squeeze	A line was drawn between the posterior superior iliac spine and the greater trochanter; the upper electrode was placed approximately 5 cm above and laterally to the midpoint of this line, given the diagonal direction the muscle fibers course. The lower electrode was positioned approximately 5 cm below and medially to the same line.	3RM	Barbell hip thrust presented a higher mean GMax activation than back and split squat
Marchetti et al. 2018	n-line and Traditional Lunge	Prone position with knee 90° flexion	50% on the line between the sacral vertebrae and the greater trochanter	10RM	Both exercises presented similar GMax activation
Collazo Garcia et al. 2018	Barbell Hip Thrust with feet position variations	Prone position with knee 90° flexion	50% on the line between the sacral vertebrae and the greater trochanter	40%RM	Rotation feet variation presented the higher GMax activation

GMax = Gluteus maximus; 1RM = maximum repetition.

Table 1. Continued…

References	Exercises	EMG normalization method	Electrode placement	Testing Load	Main Findings
Yavuz and Erdag, 2017	Back Squat	Extended and flexed knee position with slightly outward rotated legs and hyperextension position (~20°)	50% on the line between the sacral vertebrae and the greater trochanter	80, 90 and 100%RM	Higher GMax activation with higher loads (90 and 100%RM)
Andersen et al. 2017	Barbell Deadlift, Hex-bar Deadlift, and Barbell Hip Thrust	Prone position with straight legs	50% on the line between the sacral vertebrae and the greater trochanter	1RM	Barbell hip thrust presented the higher GMax activation
McCurdy et al. 2017	Bilateral Squat, Modified-Single-leg Squat, and Stiff-leg Deadlift	Prone position with knee 90° flexion	Gluteus maximus belly parallel with the muscle fibers	Bilateral and modified-single-leg squat 3RM Stiff-leg deadlift 8RM	Greater GMax activation in the modified-single-leg squat compared to others
Da Silva et al. 2017	Partial (0-90°) and Full (0-140°) Back Squat	Prone position with knee 90° flexion against resistance	50% on the line between the sacral vertebrae and the greater trochanter	10RM	Partial back squat presented higher GMax activation
Evans et al. 2017	Back Squat and Belt Squat	Glute squeeze	50% on the line between the sacral vertebrae and the greater trochanter	5RM	Higher GMax activation found for back squat
Contreras et al. 2016	Barbell Hip Thrust with Traditional, Band and American style	Standing glute squeeze or prone bent-leg hip extension against manual resistance	Upper gluteus maximus: superior and lateral to a line drawn between the posterior superior iliac spine and the posterior greater trochanter; Lower gluteus maximus: inferior and medial to a line drawn between the posterior superior iliac spine and the posterior greater trochanter	10RM	Higher GMax activation found in the traditional Barbell hip thrust than others
Contreras et al. 2016	Back Squat and Barbell Hip Thrust	Standing glute squeeze or prone bent-leg hip extension against manual resistance	Upper gluteus maximus: superior and lateral to a line drawn between the posterior superior iliac spine and the posterior greater trochanter; Lower gluteus maximus: inferior and medial to a line drawn between the posterior superior iliac spine and the posterior greater trochanter	10RM	Barbell hip thrust presented higher GMax activation
Contreras et al. 2015	Parallel and Full Back Squat and Front Squat	Standing glute squeeze or prone bent-leg hip extension against manual resistance	Upper gluteus maximus: superior and lateral to a line drawn between the posterior superior iliac spine and the posterior greater trochanter; Lower gluteus maximus: inferior and medial to a line drawn between the posterior superior iliac spine and the posterior greater trochanter	10RM	No differences found between exercises
Yavuz et al. 2015	Front and Back Squat	Extended and flexed knee position with slightly outward rotated legs and hyperextension position (~20°)	50% on the line between the sacral vertebrae and the greater trochanter	1RM	No differences found between exercises
Gomes et al. 2015	Back Squat with and without knee wraps	Prone position with knee 90° flexion	50% on the line between the sacral vertebrae and the greater trochanter	60%RM and 90%RM	Knee wrap decreased GMax activation and higher load-induced higher GMax excitation
Aspe and Swinton, 2014	Back and Overhead Squat	Horizontal position anchored at the ankles and supported across hip joint on a glute-hamstring apparatus	50% on the line between the sacral vertebrae and the greater trochanter	60, 75 and 90% 3RM	Higher GMax activation found in back squat compared to overhead for all intensities tested
Simenz et al. 2012	Step-Up, Crossover Step-Up, Diagonal Step-Up, and Lateral Step-Up	Lying prone with 70° hip flexion on a decline bench	muscle belly one-third of the distance from the second sacral spine to the greater trochanter.	6RM	Step-up presented higher GM activation
Escamilla et al. 2002	Sumo and Conventional Deadlift	EMG data normalization averaged over each of the trials	50% on the line between the sacral vertebrae and the greater trochanter	12RM	No differences found between exercises

GMax = Gluteus maximus; 1RM = maximum repetition.

Table 2. Summary of the pooled average of the mean maximum voluntary isometric contraction percentage (%MVIC) for Gluteus maximus in the different exercises. Values are given as an average of pooled mean and the standard deviation.

Exercise	Number of studies	Number of subjects	Average (mean %MVIC)	Minimum-maximum (%MVIC)
Back Squats (all variations)	10	156	53.10 ± 25.12	13 - 92.70
Deadlifts (all variations)	4	78	61.02 ± 28.14	35 - 94
Hip Thrusts (all variations)	5	58	75.41 ± 18.49	49.2 - 105
Front Squat	2	38	40.54 ± 4.73	37.2 – 43.89
Belt Squat	1	31	71.34 ± 29.42	-
Modified Single-leg Squat	1	18	65.6 ± 15.1	-
Step-ups (all variations)	1	15	125.09 ± 55.26	104.19 - 169.22
Lunges (all variations)	1	15	66.5 ± 0.7	66 - 67
Overhead Squat	1	14	39.75 ± 29.91	-
Split Squat	1	12	70 ± 15	-

Table 3. Comparison of Gluteus maximus (GMax) activation for all exercise variations. Classification of muscle activation is givens as low (0-20% MVIC), moderate (21-40% MVIC), high (41-60% MVIC) and very high (>60% MVIC). Values are given as mean or the average of pooled mean of maximum voluntary isometric contraction percentage (%MVIC) and the standard deviation.

Classification	Level of activation	Exercise	Average (%MVIC)
1º	Very high	Step-Up	169.22 ± 101.47
2°	Very high	Lateral Step-Up	114.25 ± 54.74
3°	Very high	Diagonal Step-Up	113.21 ± 43.54
4°	Very high	Crossover Step-up	104.19 ± 33.63
5°	Very high	Hex Bar Deadlift	88 ± 16
6°	Very high	Rotation Barbell Hip Thrust	86.18 ± 34.3
7°	Very high	Traditional Barbell Hip Thrust	82.37 ± 18.65 (Lower GM: 69.5/Upper GM: 86.7)
8°	Very high	American Barbell Hip Thrust	73.65 ± 22.98 (Lower GM: 57.4 ± 34.8/ Upper GM: 89.9 ± 32.4)
9°	Very high	Belt Squat	71.34 ± 29.42
10°	Very high	Split Squat	70 ± 15
11°	Very high	In-line Lunge	67 ± 11
12°	Very high	Traditional Lunge	66 ± 13
13°	Very high	Pull Barbell Hip Thrust	65.87 ± 23.28
14°	Very high	Modified Single-leg Squat	65.6 ± 15.1
15°	Very high	Traditional Deadlift	64.50 ± 41.72
16°	Very high	Band Hip Thrust	64.2 ± 21.21 (Lower GM: 49.2 ± 26.5/ Upper GM: 79.2 ± 29.9)
17°	High	Parallel Back Squat	59.76 ± 22.52
18°	High	Feet-away Barbell Hip Thrust	51.38±17.93
19º	High	Front Squat	40.54 ± 4.73
20°	High	Stiff-Leg Deadlift	40.5 ± 18.8
21°	Moderate	Overhead Squat	39.75 ± 29.91
22°	Moderate	Sumo Deadlift	37 ± 28
23°	Moderate	Partial Back Squat	28.16 ± 10.35
24°	Moderate	Full Back Squat	26.56 ± 12.33

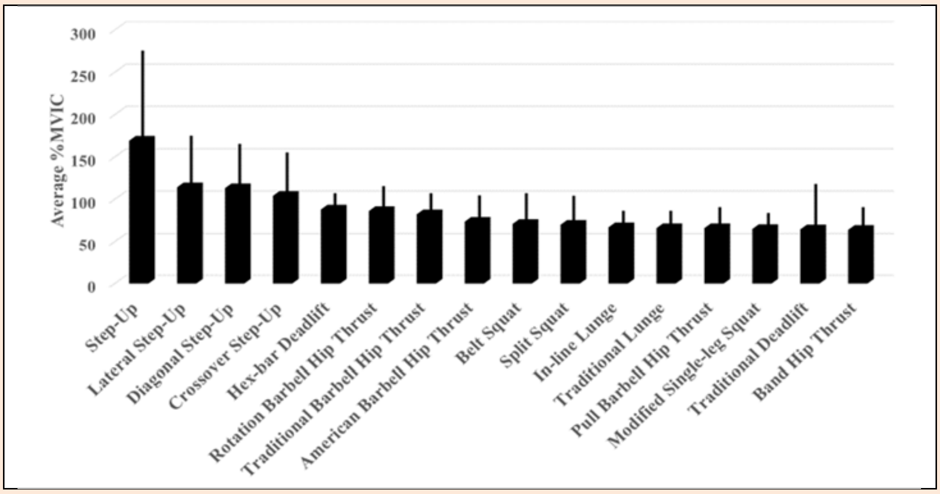

Figure 2. Gluteus maximus exercises with very high average activation (>60%MVIC).
MVIC = maximum voluntary isometric contraction).

Discussion

The results of this systematic review have shown that GMax activation varied among the exercises investigated. In general, the step-up exercise and its variations present the highest levels of GMax activation (>100% of MVIC) followed by several loaded exercises and its variations, such as deadlifts, hip thrusts, lunges, and squats, that presented a very high level of GMax activation (>60% of 1RM). It was observed that several factors, including relative external load, movement velocity, level of fatigue, the mechanical complexity of the exercise, and the need for joint stabilization, might directly influence GMax activation.

The exercise that elicited the highest activation levels of the GMax was the step-up and its variations [lateral, diagonal, and cross-over step-up] (Simenz et al., 2012). All four exercises are unilateral and require weight-bearing from the practitioner; therefore, during these exercises, the GMax is responsible for extending the hip joint, while simultaneously maintaining the pelvis level controlling excessive femur adduction and medial rotation (Baker et al., 2014; Blemker and Delp, 2005; Macadam et al., 2015). According to Macadam et al. (2015), the higher excitatory demand for step-up and its variations are associated with the need to stabilize the knees and hip during the upward and downward movement (the more significant synergistic activity of the gluteus medius). However, these exercises are considered difficult to perform and have a high stabilizing demand for most beginning and intermediate practitioners; even for the experienced practitioner, the higher stability demand may limit the load used, and therefore, may hinder maximal strength and hypertrophy development (Behm and Anderson, 2006).

The back squat exercise and its variations are widely used in strength training with goals of increasing strength and lower limb muscle hypertrophy (Clark et al., 2012). This fact was demonstrated here by a large number of studies included, which investigated different variations of the squat (10 articles). In our results, squats were classified as high GMax. However, we found significant variations in the classification between the different types of squats (ranging from low [13% of MVIC] to very high GMax activation [92.7% of MVIC]). Several factors, such as barbell position (front, high/low bar back squat), stance width, and the depth of squat, are the main factors affecting GMax activation during the squat. For example, Paoli et al. (2009) suggested that larger stance widths (1,5 and 2x great trochanter distance) are necessary for greater activation of the GMax during the back squat. Regarding the effect of squat depth on GMax activity, the results are contradicting. Caterisano et al. (2002) compared three different squat depths (partial: ~45° of knee flexion; parallel: ~90° of knee flexion, and full: ~135° of knee flexion) using 100 to 125% of subject's body weight as external resistance. Their results suggested that the full squat elicited greater GMax activation than the parallel and partial back squat. However, their main limitation was the lack of equalization of external load by the depth investigated. Contreras et al. (2016a) found no significant difference between full and parallel back squats for any of the GMax portions evaluated. More recently, Da Silva et al. (2017) demonstrated that the partial squat elicited higher GMax activation than the full squat variation when external loads are equated to squat depth. GMax relative contribution to hip extensor moment may be reduced in positions of greater squat depth (Vigotsky et al., 2016; Hoy et al., 1990; Neumann, D. A. 2010). Nevertheless, chronic studies have suggested that deeper squats, or a combination of different ranges of motion, induce the most substantial functional and muscular gains, possibly due to more considerable time under tension, mechanical tension, and longer muscle length (Bloomquist et al., 2013; Kubo et al., 2019; Bazyler et al., 2014).

The barbell hip thrust exercise and its variations are expected to demonstrate higher GMax excitation levels when compared to any exercise that includes simultaneous knee and hip flexion/extension movement, such as squats and their variations (Contreras et al., 2015b; Contreras et al., 2016b). Regarding the hip thrust and its variations, GMax activation varied between 49.2 and 105% of MVIC. These results are similar to a recent review performed by our group (Krause Neto et al., 2019), where mean GMax activity ranged between 55 and 105% of MVIC. The foot position is the main factor affecting GMax activation during the barbell hip thrust. For example, Collazo Garcia et al. (2018) compared the GMax activation between the different variations of barbell hip thrust. They observed the highest GMax activation when subjects were oriented to intend to rotate the foot outward. Additionally, Kang et al. (2016) found placing the foot at 30° of hip abduction presented higher GMax activation than 15 and 0° of hip abduction during a bodyweight hip bridge. Another interesting fact is that barbell hip thrusts elicit high and very high GMax activation even when relative low loads are lifted. Collazo Garcia et al. (2018) used 40% of 1RM and obtained high and very high levels of GMax activation in the variations of hip thrusts investigated. Delgado et al. (2019) observed that barbell hip thrust performed at 60 kg (~36% of 1RM) elicited similar GMax activation than Romanian deadlift and back squat at 1RM.

The reader should be aware of the number of methodological limitations present in the studies included in this systematic review: (1) the electrode placement, the EMG signal processing, movement phase analyzed and normalization varied between studies, therefore, may have influenced the results obtained in the systematic review; (2) a heterogeneous sample composed of studies that investigate women and/or men may suffer different influences; (3) the variation of the loads used (40% to 100% maximum) may alter the activity levels of GMax as presented by Yavuz and Erdag (2017); and (4) different levels of training experience and familiarization with the exercises tested may have influenced the EMG levels that were investigated.

Conclusion

Despite the limitations of the present review, we observed that several exercises and variations elicited very high levels of GMax activity. Therefore, it is reasonable to suggest that the strength and conditioning coach should select in a variety of exercises, the one that most fit-on clients' individual needs.

Other factors such as exercise kinetics and kinematics, relative external load, movement velocity, range of motion, level of fatigue, the mechanical complexity of the exercise (open or closed kinetic chain; weight bearing or non-weight bearing) should be considered when selecting an appropriate exercise for strengthening the GMax.

Therefore, this systematic review demonstrated that the step-up exercise and its variations present the highest levels of muscle excitation of GMax followed by several bilateral exercises and its variations, such as deadlifts, hip thrusts, and squats. GMax activity may vary significantly according to changes in technique during the exercise.

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Key points

- The step-up and its variations may elicit the highest level of Gmax activation possibly to the stabilization requirement of the exercise.
- Several bilateral exercises (e.g. hip thrusts, squats, deadlifts, and lunges) can provide very high level of GMax activation.
- The external load, movement velocity, level of fatigue, the mechanical complexity of the exercise, and the need for joint stabilization, might directly influence GMax activation.
- Further research may investigate the best practices for normalizing GMax activation.

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