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SYSTEMATIC REVIEW

EXAMINATION OF GLUTEUS MAXIMUS ELECTROMYOGRAPHIC EXCITATION ASSOCIATED WITH DYNAMIC HIP EXTENSION DURING BODY WEIGHT EXERCISE: A SYSTEMATIC REVIEW

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ABSTRACT

Background: Hip extension is an important action in daily activities (standing, stepping and walking) and sporting actions (running, sprint-running and jumping). Though several different exercises exist, a comprehensive understanding of which exercises best target the gluteus maximus (Gmax) and the magnitude of muscular excitation associated with each exercise is yet to be established.

Purpose: The purpose of this systematic review was to describe the electromyographic (EMG) excitation of the Gmax during body weight exercises that utilize hip extension.

Methods: A systematic approach was used to search Pubmed, Sports Discuss, Web of Science and Science Direct using the Boolean phrases (gluteal OR gluteus maximus) AND (activity OR excitation OR activation) AND (electromyography OR EMG) AND (hip extension). Articles that examined injury-free participants of any age, gender or excitation level were included. Articles were excluded when not available in English, where studies did not normalize EMG excitation to maximum voluntary isometric contraction (MVIC), where a load or resistance was added to the exercise, or where no hip extension occurred. Exercises were grouped into vertical and horizontal (anteroposterior or posteroanterior) force vectors.

Results: Thirty-nine studies of high methodological quality were retained for analysis. Twenty-five exercises were performed in the vertical vector (average: 33.4% MVIC, highest: single leg wall squat 86% MVIC), fourteen exercises were performed in the horizontal (anteroposterior) force vector (average: 32.8% MVIC, highest: single leg bridge 54.2% MVIC, while thirty-eight exercises were included in the horizontal (posteroanterior) vector (average: 30.4% MVIC, highest: plank with bent leg hip extension 106.2% MVIC).

Limitations: The differences in subject's backgrounds, exercise technique and the methodological approaches varied between studies, most notably in the different positions used for obtaining MVIC, which could have dramatically impacted normalized levels of gluteal activation.

Conclusion: The findings from this review provide an indication of Gmax muscle excitation generated by a variety of hip extension body weight exercises, which may assist practitioners in making exercise selection decisions for programming.

Keywords: gluteal musculature, hip strengthening, force vector, EMG, movement system

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INTRODUCTION

Hip extension is an important joint action in daily activities (standing, stepping and walking) and sporting actions (running, sprint-running and jumping). The hip extensor musculature are capable of producing the highest torque compared to any other muscle group involved in hip movement.[1] Hip extension primarily involves the gluteus maximus (Gmax), hamstrings (long head of biceps femoris, semimembranosus, and semitendinosus), and posterior head of the adductor magnus.[1,2] Recruitment of the Gmax and associated hip extensor muscles, coupled with efficient movement are required for optimal hip extension force production.[3] Although several muscles contribute to hip extension, the focus for this article is on the Gmax musculature and its role in hip extension during body weight exercise.

Though several different exercise protocols exist, scientific evaluation of their specific effects on the Gmax has yet to establish which exercises best isolate the musculature and what level of muscular excitation is elicited. Electromyography (EMG) is a tool that provides insight into how the neuromuscular system behaves via amplitude information regarding the timing characteristics and muscle excitation levels for a given recording condition.[4,5] Historically, exercises have been examined through EMG analysis with the general consensus assumed that exercises producing higher levels of muscular excitation are associated with greater long-term strength and size increases.[6,7] Though debate remains about the application of EMG in a practical context [4] it is a commonly implemented method within the literature and therefore may be used as a guideline to assist in understanding musculature excitation.

Weakness and imbalanced strength in the Gmax is associated with multiple lower extremity injuries and lower back pain[8] which can necessitate substitution by synergist musculature.[9] Consequently, practitioners often choose to incorporate Gmax targeted exercise in both rehabilitation and sport settings by starting with unloaded (i.e. body weight only) exercises. An extensive variety of body weight hip extension exercises are used for training, both in athletic performance and in rehabilitation programming. As one alters the body's position during the different hip extension exercise options, this will result in a change in the amount of body mass being moved by the hip musculature and the orientation of the gravitational force-vector. Selecting exercises by taking into regard the direction of the force-vector [10,11] (i.e. horizontal vs vertical, Figure 1) may play an important role in developing different and specific functional adaptations.[12] Moreover, specificity of movement promotes intermuscular coordination which has been shown to increase transference to sport performance.[13] Therefore, classifying hip extension body weight exercises by the respective force vectors may be important for best exercise selection for activity type and conversion into performance outcomes.

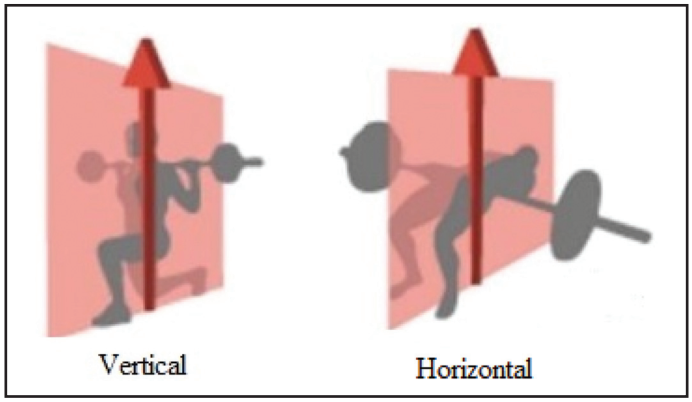

Figure 1. *Force-vector directions occurring during a vertical exercise (i.e. vertical loading with respect to anatomical position, also known as an axial vector) and a horizontal exercise (i.e. horizontal loading with respect to anatomical position, also known as an anteroposterior vector). Horizontal oriented exercises can be further challenged by the direction of the horizontal loading from the opposite direction to anteroposterior, known as the posteroanterior vector.*

It is important to take into consideration the force-vector associated with different exercises when developing programming for rehabilitation or performance enhancement as different force-vector exercises have been shown to elicit differences in Gmax EMG amplitudes. This was certainly the case in loaded hip extension exercises with equated 10 repetition maximum loads that resulted in a significant greater amount of mean lower and upper Gmax excitation found in the horizontal vector exercise (barbell hip thrust, 40.8-69.5% MVIC) compared to the vertical vector exercise (barbell back squat 14.9-29.4% MVIC).[14] Similarly, Gmax excitation was 16% higher during the barbell hip thrust (horizontal) compared to the hex bar deadlift (vertical) with 1RM loading.[15] Whether these differences occur in unloaded hip extension exercises is unknown. Therefore, the purpose and focus of this systematic review was to describe the EMG excitation of the Gmax during body weight exercises that utilize hip extension. Exercises were grouped by force vector position to assist practitioners in making decisions for exercise selection that targets Gmax excitation.

METHODS

Literature Search Strategies

The review was conducted in accordance with PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-analyses) statement guidelines.[16] A systematic search of the research literature was undertaken for studies that investigated EMG amplitude (given as mean %MVIC) for the Gmax in body weight exercises that utilised dynamic hip extension. Studies were found by searching Pubmed, Sports Discuss, Web of Science and Science Direct electronic databases from inception to November 1st 2017 using the following Boolean search phrases: (gluteal OR gluteus maximus) AND (activity OR activation) AND (electromyography OR EMG) AND (hip extension). Additional studies were also found by reviewing the reference lists from retrieved studies.

Inclusion and Exclusion Criteria

Articles that examined injury-free participants of any age, sex or activity level were included. No restrictions were imposed on publication date or publication status. Studies were limited to English language. Studies were excluded that did not normalize EMG excitation to %MVIC or did not present the results as numbers (i.e. results presented as figures). This review focussed on exercises performed without any additional load, therefore only body weight exercises were included and studies which contained an external load (e.g. barbell, dumbbell, band, and machine) were excluded. Plyometric or hopping movements were also excluded as they are performed with higher acceleration, therefore they have an advantage in terms of eliciting high levels of gluteal excitation. Moreover, plyometric exercises are higher end performance type exercises and should be used once an individual exhibits prerequisite strength levels (eccentric) which includes mobility and stability.

Study Selection

One reviewer (PM) searched the databases and selected studies. A second reviewer (EF) was available to assist with study eligibility. No disagreements about the appropriateness of an article were encountered. A search of electronic databases and a scan of article reference lists revealed 355 relevant studies, with an additional 14 studies found via hand searches of references lists (Figure 2). After removing duplicate studies (n = 68), screening titles (n = 78) and abstracts (n = 149), 49 studies were retained. Following full-text screening, a further 10 studies were excluded (6 studies were not normalised to MVIC, 4 studies reported results as figures), thereby, 39 studies were retained for this review.

Methodological Quality Score

Methodological quality was assessed using the quality index of Downs and Black[17] modified version.[18] A value of 0 or 1 was assigned to the different subcategories of the following items: reporting, external validity, and internal validity. A total score < 10/17 was considered to be low quality, while scores ≥ 10/17 were presumed to be high quality.[18]

RESULTS

Quality assessment scores of the thirty-nine articles included ranged from 10 to 14, with an average score of 11.6 out of 17, indicating a high methodological quality for the studies reviewed (Appendix 1). There were a total number of 938 subjects who performed 77 total exercise variations. Appendix 1 summarises all studies included. All studies used surface electrodes, with the exception of Selkowitz, Beneck, Powers [19] who used fine wire electrodes. Two studies[19,20] reported the superior (upper) and inferior (lower) regions of the Gmax, while the remaining Gmax values were obtained from electrodes positioned on muscle belly (descriptions of electrode placement are given in Appendix 1). Results are presented within vertical and horizontal force vector tables with horizontal exercises further sub-divided into anteroposterior and posteroanterior due to high number of exercises within each sub-division). Results for the same exercise have been averaged from the combined totals to present a mean percentage of MVIC and mean range value for the exercise. However, due to differences between study methodologies

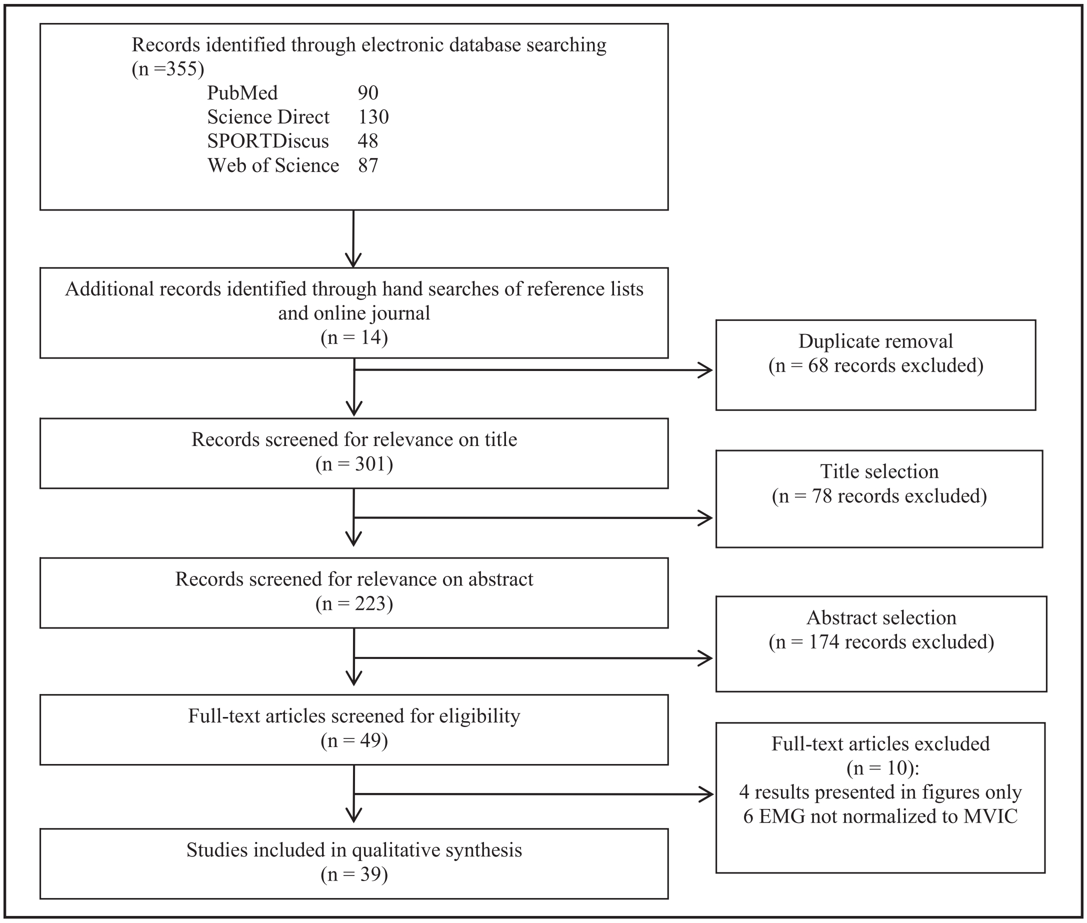

Figure 2. *PRISMA diagram of article selection through the different phases of the systematic review.*

caution should be used for interpreting the findings, therefore, the mean values should be interpreted as a guideline. Exercises were grouped by the magnitude of mean Gmax excitation and stratified into the four levels of activity: 0-20% MVIC was considered low muscle excitation, 21-40% MVIC was considered moderate muscle excitation, 41-60% MVIC was considered high muscle excitation, and greater than 60% MVIC was considered very high muscle excitation.[21,22] 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. Table 4 provides a summary of average %MVIC for Gmax in the different force vector positions.

Vertical force vector

The Gmax excitation for exercises performed in the vertical force vector can be found in Table 1. Twenty-five different exercises were performed in this force vector with the most common exercises being the single leg squat (9), lunge (7), and lateral step up (6). The highest mean excitation was found in the single leg wall squat with other leg knee extended (86 ± 43% MVIC) and the lowest activity occurred in the squat with 0° trunk flexion (6.1 ± 4.0% MVIC). Eight exercises were classified as low excitation, ten were moderate excitation, four were high excitation, and three were very high excitation. Of note, variations of the deadlift exercises were included in this force vector although the force vector is not truly vertical and crosses with the anteroposterior force vector.

Horizontal force vector (Anteroposterior)

Information regarding the Gmax excitation for the anteroposterior force vector can be observed in Table 2. Fourteen different exercises were performed in this force vector with the most common exercises being the single leg bridge (6) and two-legged bridge (6). The highest absolute excitation was found in the

Table 1. *Comparison of muscle excitation in the Gluteus Maximus for all vertical force vector exercises. Values given as the mean and the standard deviation.*

Classification level of %MVIC	Exercise	Number of studies	Number of subjects	Mean %MVIC of Gmax	Range % MVIC of Gmax
0-20%	Squat with 0° trunk flexion[58]	1	20	6.1 ± 4.0	Not available
	Squat with 15° trunk flexion[58]	1	20	6.3 ± 4.0	Not available
	Squat with 30° trunk flexion[58]	1	20	8.0 ± 4.9	Not available
	Lunge with pelvic compression belt[48]	1	20	13.9 ± 7.7	Not available
	Squat[19,48,55,]	3	58	14.4 ± 4.3	10.5-21.7
	Forward step up and over[42]	1	44	16.5 ± 11.7	Not available
	Lateral step down[28]	1	34	16.5	8.4-24.6
	Lunge with trunk extension[41]	1	10	19.3 ± 11.8	Not available
21-40%	Lunge with trunk flexion[41]	1	10	22.3 ± 12.0	Not available
	Lunge[19, 31, 41, 43, 42, 44, 48]	7	185	22.8 ± 12.3	11-44
	Forward step down[28]	1	34	23.1	19.0-27.2
	Lateral lunge[43, 45]	2	61	26.5 ± 14.5	12-41
	Single leg wall squat, other leg knee flexed[28]	1	34	26.8	21.6-32.0
	Single leg mini squat, other leg knee flexed[24, 28]	2	57	34.6 ± 16.3	20.3-57
	Single leg squat with pelvic compression belt[48]	1	20	35.5 ± 21.7	Not available
	Lateral step up[24, 25, 28, 31, 39, 52]	6	143	36.0 ± 17.8	16-63.8
	Single leg deadlift with pelvic compression belt[48]	1	20	36.3 ± 21.9	Not available
	Forward step up [19, 24, 25, 28, 44, 52]	6	119	38.7 ± 19.5	15.7-74
41-60%	Single leg squat[25, 26, 27, 42, 43, 44, 48, 49, 50]	9	227	43.2 ± 14.9	18.9-81.2
	Single leg deadlift[27, 43, 48]	3	65	48.6 ± 14.6	27.9-59
	Transverse lunge[43]	1	21	49 ± 20	Not available
	Retro step up[24]	1	23	59 ± 35	Not available
>60%	Skater squat[25]	1	24	66.2	Not available
	Single leg squat with rotation[49]	1	9	78 ± 45	Not available
	Single leg wall squat, other leg knee extended [24]	1	23	86 ± 43	Not available

Gmax = Gluteus Maximus **MVIC** = maximum voluntary isometric contraction

Table 2. *Comparison of muscle excitation in the Gluteus Maximus for all anteroposterior force vector exercises. Values given as the mean and the standard deviation.*

Classification level of %MVIC	Exercise	Number of studies	Number of subjects	Mean %MVIC of Gmax	Range % MVIC of Gmax
0-20%	Bridge with feet on a swiss ball and hamstring curl[56]	1	26	10.9	Not available
	Bridge with feet on a swiss ball[56]	1	26	13.0	Not available
	Bridge with hamstring curl[56]	1	26	18.5	Not available
	Bridge with knees extended and feet on a swiss ball[56]	1	59	20 ± 14	Not available
21-40%	Bridge[19, 29, 31, 40, 56, 57,]	6	177	23.3 ± 8.8	16.4-41.5
	Single leg bridge with foot on bosu[56]	1	26	28.4	Not available
	Bridge with verbal and tactile cues[29]	1	15	33.0	Not available
	Supine manual resisted hip extension[2]	1	26	34.7	Not available
	Single leg bridge[2, 19, 25, 31, 56, 57]	6	153	39.9 ± 7.6	32.6-54.2
41-60%	Single leg bridge. DOM leg 135° knee flexion with dorsiflexed ankle. Non- DOM leg knee relaxed in flexion and femur vertical[30]	1	28	40.4 ± 24.6	Not available
	Single leg bridge. DOM leg 90° knee flexion with foot flat. Non-DOM leg knee relaxed in flexion and femur vertical[30]	1	28	47.2 ± 28.1	Not available
	Single leg bridge. DOM leg 135° knee flexion with foot flat. Non-DOM leg knee extended[30]	1	28	47.4 ± 24.8	Not available
	Single leg bridge. DOM leg 90° knee flexion with dorsiflexed ankle. Non- DOM leg knee relaxed in flexion and femur vertical[30]	1	28	49.1 ± 26.4	Not available
	Single leg bridge. DOM leg 90° knee flexion with foot flat. Non-DOM leg knee extended[30]	1	28	51.0 ± 28.1	Not available

DOM = dominant **Gmax** = Gluteus Maximus **MVIC** = maximum voluntary isometric contraction

single leg bridge (54.2% MVIC), though when this exercise was averaged from six studies the mean activity was 39.9% MVIC. The lowest excitation occurred in the bridge with feet on a gymnastics ball exercise (13.0% MVIC). Four exercises were classed as low excitation, five were moderate excitation and five were high excitation.

Horizontal force vector (Posteroanterior)

Information regarding the Gmax excitation for the posteroanterior force vector can be found in Table 3. Thirty-eight different exercises were performed in this force vector. The highest mean excitation was found in the plank with bent leg hip extension (106.2% MVIC) followed by prone hip extension with upper body on

Table 3. *Comparison of muscle excitation in the Gluteus Maximus for all posteroanterior force vector exercises. Values given as the mean and the standard deviation.*

Classification level of %MVIC	Exercise	Number of studies	Number of subjects	Mean %MVIC of Gmax	Range % MVIC of Gmax
0-20%	Prone hip extension from 30° hip flexion to 10° hip extension[46]	1	16	10.9 ± 3.3	Not available
	Prone hip extension from 30° hip flexion with verbal cue to activate the hamstrings[37]	1	11	11.2 ± 5.2	Not available
	Prone hip extension from 30° hip flexion[33, 37]	2	36	14.4 ± 4.4	9.7-18.9
	Prone hip extension up to 20° with 90 ° knee flexion[20]	1	20	15.9 ± 4.2	11.7-20.1
	Prone hip extension with knee extension[34, 51]	2	41	15.5 ± 2.8	12.7-18.3
	Prone hip extension with 90 ° knee flexion and neutral hip position[32, 34]	2	52	18.6 ± 4.5	14.1-23.1
	Prone hip extension from 0° hip flexion[33]	1	15	19.7 ± 7.9	Not available
21-40%	Prone hip extension with knee flexion with hip abducted 0°[8]	1	30	20.2 ± 8.6	Not available
	Quadruped hip extension bent leg non-DOM[25]	1	24	21.0	Not available
	Prone hip extension with lateral hip rotation and knee flexion[34]	1	31	21.2 ± 12.0	Not available
	Prone hip extension from hip flexion of 30° with verbal cues to activate the glutes[37]	1	11	21.6 ± 9.8	Not available
	Prone hip extension from 15° hip flexion[33]	1	15	22.5 ± 9.4	Not available
	Prone hip extension with 90 ° knee flexion and 15° hip abduction[32]	1	21	22.5± 13.6	Not available
	Prone hip extension with lateral hip rotation and knee extension[34]	1	31	22.5 ± 10.4	Not available
	Prone hip extension with knee flexion with hip abducted 15°[8]	1	30	23.4 ± 9.9	Not available
	Prone hip extension to hip extension of 10°[54]	1	15	23.9 ± 18.5	Not available
	Prone hip extension to hip extension of 10° with abdominal drawing-in[54]	1	15	24.4 ± 14.3	Not available
	Prone hip extension up to 20° with 90 ° knee flexion with abdominal bracing[20]	1	20	26.3 ± 9.7	16.6-36.0
	Back extension with extended knees and hands behind head[53]	1	18	26.5 ± 13.6	Not available
	Back extension with extended knees and hands across chest[53]	1	18	28.3 ± 14.5	Not available
	Reverse hyperextension[38, 47]	2	27	28.7 ± 7.3	20.3-38.8
	Prone hip extension with knee flexion with hip abducted 30°[8]	1	30	29.6 ± 11.5	Not available
	Quadruped hip extension with knee extended[19]	1	20	29.9 ± 1.3	28.5-31.2
	Prone back/torso extension[38, 47]	2	27	31.8 ± 6.2	23.8-44.9
	Quadruped hip extension with knee flexed[19]	1	20	32.2 ± 2.1	30.1-34.3
	Prone hip extension to hip extension of 10° with pelvic tilt > 15°[54]	1	15	32.5 ± 21.3	Not available
	Back extension with flexed knees 90° and hands across chest[53]	1	18	34.8 ± 20.6	Not available
	Back extension with flexed knees 90° and hands behind head[53]	1	18	36.6 ± 22.6	Not available
	Reverse hyperextension with lumbopelvic control strategy[38]	1	13	38.8 ± 24.1	Not available
41-60%	Prone hip extension with 90 ° knee flexion and 15° hip abduction and 20° hip external rotation[32]	1	21	41.0 ± 23.6	Not available
	Prone hip extension to hip extension of 10° with abdominal drawing-in with pelvic tilt > 15°[54]	1	15	45.9 ±33.7	Not available
	Prone hip extension with upper body on table and abdominal drawing-in[35]	1	16	47.5 ± 19.8	Not available
	Prone hip extension with upper body on table[35, 36]	2	34	53.1 ± 9.2	43.9-62.3
	Quadruped arm and leg raise[31]	1	30	56.2 ± 22	Not available
	Prone hip extension with body on floor[36]	1	18	56.5 ± 20.2	Not available
	Quadruped hip extension bent leg DOM[25]	1	24	59.7	Not available
>60%	Prone hip extension with upper body on table and flexed contralateral knee joint on a chair[35]	1	16	66.4 ± 25.8	Not available
	Plank with bent leg hip extension[25]	1	24	106.2	Not available

DOM = dominant **Gmax** = Gluteus Maximus **MVIC** = maximum voluntary isometric contraction

table and flexed contralateral knee joint on a chair (66.4 ± 25.8% MVIC). The lowest excitation occurred in the prone hip extension from hip flexion of 30° (9.7 ± 2.9% MVIC). Seven exercises were classed as low excitation, twenty-two were moderate excitation, seven were high excitation, and two were very high excitation.

Summary of force vectors

Details of Gmax excitation for all positions are summarized in Table 4. The vertical position produced the highest average excitation (33.4% MVIC) followed by the anteroposterior (32.8% MVIC) and posteroanterior (31.5% MVIC). A limitation of positional grouping by force vector is that similar average excitation levels were found between vectors due to a wide variation in the different exercises. The posteroanterior force vector had the absolute highest excitation value (106.2% MVIC) for the plank with bent leg hip extension exercise while the vertical vector had the lowest excitation value

Table 4. *Summary of average %MVIC for Gluteus Maximus in different force vector positions. Values given as the mean and the standard deviation.*

Force vector position	Vertical	Horizontal	
		Anteroposterior	Posteroanterior
Number of studies	21	9	18
Number of subjects	534	255	363
Number of exercises	25	14	38
Gmax average %MVIC	33.4	32.8	30.4
Gmax range %MVIC	6.1-86.0	10.9-54.2	9.7-106.2

Gmax = Gluteus Maximus, MVIC = maximum voluntary isometric

(6.1% MVIC) for the squat with 0° trunk flexion exercise.

DISCUSSION

The purpose of this systematic review was to quantify the EMG excitation of the Gmax musculature during body weight hip extension exercises. Findings from the thirty-nine studies reviewed showed that the level of Gmax EMG excitation ranged from 6.1% to 106.2% MVIC. The wide range of Gmax EMG found from hip extension exercises in this review is comparable to the levels (4% to 103% MVIC) found in Gmax excitation during hip abduction and external rotation exercises reported by Macadam, Cronin, Contreras [23] Pooled results from in the three force vectors show a similar average level of EMG excitation between vectors: vertical (33.4%), anteroposterior (32.8%) and posteroanterior (30.5%). However, when looking at the range of EMG excitation it would seem that levels can be affected by changes in body position, which changes the direction in which force is applied to in relation to the body and the complexity of the exercise.

Vertical force vector

Twenty-five exercises were performed in the vertical vector (average: 33.4% MVIC, highest mean: single leg wall squat 86.0% MVIC). Unilateral versions of a vertical oriented exercise resulted in greater Gmax excitation than the bilateral version. This can be seen from all versions of the squat which resulted in small EMG excitation levels, compared to the single leg squat which resulted in levels of moderate, high and very high during differing versions. The single leg squat was the most used exercise (9 studies) in this vector and though its average excitation level was high (47.8% MVIC), it was found to elicit a wide range of excitation (18.9-81.2% MVIC). Reasons for range of values may relate to the depth of the squat, subject's proficiency and experience of the exercise, and the position of the free leg. This is highlighted by Ayotte, Stetts, Keenan, et al. [24] who found the highest level of EMG excitation in the single leg squat when the free leg is extended from the knee (86% MVIC). While when the free leg is flexed from the knee and behind the body, i.e. the skater squat version, the level of excitation was 66.2% MVIC.[25] The single leg squat exercise was also found to result in excitation level differences between genders, with females exhibiting greater levels than males in three studies.[26-28] Females were also found to exhibit greater excitation levels in single leg wall slide, lateral step down and forward step down exercises.[28] Reasons for differences may relate to structural differences (females having an increased pelvic width to femoral length ratio) or differences in hip abductor strength requiring greater Gmax excitation to control the pelvis in the unilateral exercises.[28] All three studies assessed exercises in the vertical vector, therefore due to the greater stability requirements in this vector it is unknown if these gender differences occur in other force vectors.

A commonly used vertical exercise was the lunge (7 studies) which resulted in a small to moderate level of excitation (11-44% MVIC), thus may be suitable as an early progressive exercise from bilateral exercises due to its split-stance two point of contact providing a base of stability that challenges balance from the wide foot base. Once mastered, progression can include forward and lateral step down exercises which elicited small excitation in males and moderate excitation in females. While subsequent progressive exercises can include the forward and lateral step up exercises which resulted in moderate to high excitation levels. Step heights can be adjusted for these exercises to further increase (or decrease) the stability requirements of the exercise. When the body is upright, greater stability requirements would be expected in hip extension movements which may be reflected in this vector having the highest average EMG excitation level. However, differences in exercises mean that a wide range of EMG levels (6.1-86.0% MVIC) were found in this vector. Exercises with a greater base of stability (squats and lunges) may be implemented for more novice subjects while greater challenges can be imposed from step up exercises to the more advanced versions of single leg squats.

Horizontal force vector (Anteroposterior)

Fourteen exercises were performed in the anteroposterior force vector (average: 32.8% MVIC, highest mean: single leg bridge 54.2% MVIC). The bridge and its unilateral version were the two most used exercises (both in 6 studies) in this vector highlighting their prominence of application. The single leg bridge was found to elicit a higher range of Gmax EMG excitation level (32.6-54.2% MVIC) than the bridge (16.4-41.5% MVIC), most likely due to the greater demands (increased load required to be stabilized with one leg off the ground) imposed by a single leg base of support compared to the bilateral position. Low levels of excitation (< 20% MVIC) were found in bridging exercises where the feet are placed on a swiss ball or where subjects were required to perform a hamstring curl movement from a bridge position. Similarly, when performing a single leg bridge on a BOSU® surface, a lesser level of excitation (28.4% MVIC) was found compared to single leg bridge on the ground (32.6-54.2% MVIC). Therefore, it appears that when performing bridging exercises on an unstable surface (swiss ball or bosu), the level of Gmax excitation is decreased. When tactile and verbal cues to activate the glute muscle were given, EMG excitation levels increased (33.0% vs. 16.8% MVIC) compared to the regular bridge exercise, [29] thus should be a consideration for practitioners especially during exercise instruction in novice clients. Five single leg bridge exercises elicited high excitation levels with differing positions from the leg and foot on the ground, and with the leg in the air, resulting in small changes in levels of EMG %MVIC. Although altering the positions can be used to change the Gmax excitation level, when the dominant knee (i.e. the leg in contact on the ground) was flexed to 135° instead of 90°, hamstring excitation decreased from 58-75% to 20-23% MVIC. [30] Therefore, for subjects who may more readily recruit the hamstrings, altering the angle of the knee reduces hamstring excitation while Gmax levels remain relatively similar. However, hamstring activity was not assessed in this review. None of the exercises in this vector elicited a very high EMG amplitude, however, exercises in this vector may be suitable as early hip extension exercises as they provide a stable base of support with the body on the ground. Progression and difficulty can be increased by having the exercises performed unilaterally while being further challenged by extending the leg in the air. Performing bridging exercises on unstable surfaces decreases Gmax excitation and thus may be more suitable for targeting other muscles or goals. Additionally, compared to many of the vertical and posteroanterior exercises, the exercises performed in this vector involve a change in body position resulting in a portion of body mass supported by the floor. This reduces the total load needing to be moved by the hip musculature.

Horizontal force vector (Posteroanterior)

Thirty-eight exercises were included in the posteroanterior vector (average: 30.5% MVIC, highest mean: plank with bent leg hip extension 106.2% MVIC). Though this vector had the highest number of exercise variations, many of the exercises are similar with small changes in either hip angles or knee angles. Many of the exercise variations in this vector replicate the testing position used to obtain %MVIC, though this vector had the lowest average EMG %MVIC level. However, of all the exercises in this review, this vector had the highest individual excitation level found in the plank with bent leg hip extension resulting in 106.2% MVIC. This suggests that when the base of support is challenged in this position (i.e. a person is only supported from one foot and their elbows), Gmax excitation is greatly increased during hip extension from this position.

When performing hip extension from a quadruped position (i.e. starting with ground contact from the hands and knees), moderate to large excitation levels result. Whether the extended leg utilises knee flexion (32.2% MVIC) or extension (29.9% MVIC) resulted in similar values.[19] However, when the non-dominant leg was assessed with knee flexion (21% MVIC), a difference was found compared to the dominant leg (59.7% MVIC). [25] Though subject differences could be a factor to explain the findings between the studies, Selkowitz, Beneck, Powers [19] used indwelling electrodes compared to surface electrodes which may also account for differences in results. When the arm was raised along with the leg during the quadruped exercise, the excitation level increased (56.2 % MVIC)[31] most likely due to the greater stability challenge with less ground contact points for base support. Changes in excitation levels were also found from hip extension exercises performed with the hip in different positions. Performing hip extension from increased degrees of hip abduction (0° to 30°) was found to increase Gmax excitation by 9% [8] and by 27% (0° to 15°, also with 20° hip external rotation).[32] Furthermore, exercise performed from different hip flexion positions (0° to 20°) increased excitation by 3%,[33] while hip extension from hip external rotation increased excitation by 10%.[34] The position of the leg from the knee joint was also found to affect Gmax excitation levels, with Sakamoto, et al. [34] finding that knee flexion (23.1% MVIC) elicited higher excitation than knee extension (12.7% MVIC).

Two studies [35,36] using prone hip extensions exercises, found that Gmax excitation was increased (2-4%) when subjects performed abdominal drawing-in during the exercise. Similarly, when subjects braced their abdominals during prone hip extension, greater levels of excitation (4-15%) were found.[20] Moreover, as found during bridging exercises, when subjects were instructed to activate their glutes during prone hip extension from 30° hip flexion,[37] a greater level of Gmax excitation was found (21.6% vs. 9.7% MVIC) compared to the non-instructed version. Increased Gmax excitation was reported in reverse hyperextension (38.8% vs. 22.0%) and back/torso extensions (32.4% vs. 23.8%) when subjects performed a lumbopelvic control stabilsation strategy.[38] These findings suggest that cueing internal mechanisms can be used to elicit greater Gmax excitation levels during different hip extension exercises. Exercise performed in this vector can be used to elicit a wide range of Gmax EMG excitation. Through altering positions of the hip (flexion, abduction, external rotation), greater excitation levels can be achieved with ground base stability. Moreover, by internal cueing mechanisms subjects can increase Gmax excitation during differing prone extensions exercises. Progression can be increased by challenging the base of support through contralateral and ipsilateral arm and leg raises during quadruped exercises, with greater challenge found during the plank base of support exercise.

Limitations

The reader should be cognizant of several limitations that affect interpretation and bias, namely that the methodological approaches varied greatly between the thirty-nine studies (see Appendix 1). Studies used different testing positions (standing, prone, supine) for determination of the MVIC, which could dramatically impact normalized levels of gluteal activation. Electrode placement (superior, inferior, mid-belly) also varied among studies. Several studies investigated the same exercise, however, differences in the way the exercises were performed need to be considered when analyzing the findings. For example, the step-up height used for step-up exercises ranged between 15.0 to 20.3 cm, therefore, differing levels of EMG activation would be an expected outcome. To most thoroughly compare EMG excitation between two studies, at the very least, their MVIC positions, electrode site placements, data processing, and amplitude presentations should be identical. Furthermore, other variables such as range of motion, relative load, effort and tempo should also be similar. This review examined muscular excitation through EMG analysis which itself has limitations when interpreting findings and providing practical suggestions. EMG is a useful tool for gaining insight into the neuromuscular system, musculoskeletal modelling, and basic science work though, its practical application is not truly clear,[4] therefore, the reader needs to be cognizant of its limitations. However, despite these factors, EMG is a commonly implemented method into providing insights into how the neuromuscular system behaves and may be used as guidance to assist in understanding musculature excitation. This review summarizes information obtained from healthy subjects; therefore, vigilance is necessary when extrapolating these findings to patients with pathology. Moreover, the heterogeneity of the subjects should be considered, with differences in gender, fat mass and training status potentially affecting the findings. The risk of bias should also be noted, with three of the studies failing to adequately describe the subject's characteristics.

CONCLUSIONS

Though several limitations exist within this review, some general observations can be made as follows: 1) body weight hip extension exercises provided a wide range of Gmax EMG excitation ranging from 6.1% to 106.2% MVIC; 2) when pooled as an average, similar levels of excitation were found between force vectors though the range of excitation levels differed between vectors; 3) unilateral exercises produced higher EMG values compared to the bilateral version of the same exercise; 4) females exhibited greater EMG excitation than males in all hip extension exercises, 5) verbal and tactile cues increase Gmax EMG excitation, while bracing and drawing-in the abdominals also increase excitation levels; and, 6) hip extension exercises performed in greater degrees/angles of hip flexion, hip abduction or hip external rotation result in higher measured EMG excitation levels. The pooled averaged values for the same exercises should be interpreted as a guideline and caution should be used for interpreting their findings with further research into each exercise with the same methodology required to verify these results. Moreover, this review focused on body weight exercises, therefore, whether the loaded version of the same exercises in this review results in similar findings requires investigation. When strengthening a weaker muscle or muscle group, practitioners may wish to prescribe a gradual and progressive exercise program to ensure the targeted area is developed. Practitioners should initially consider exercises performed in the horizontal vector as they provide a large base of support and are less challenging compared to vertical vector exercises. Moreover, bi-lateral exercises should be mastered before prescribing unilateral versions. This may be of importance if individuals seek and implement a compensatory movement pattern when faced with weakness or dysfunction. Individuals may benefit from being prescribed exercises that they can perform with good technique without substitution. Subsequently, once this can be achieved, exercise difficulty can be progressed with more demanding exercises.

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Appendix 1. *Summary of all studies reviewed with EMG excitation (%MVIC) values given as the mean and the standard deviation. (n = 39)*

Author and date	Subjects (Sex, age, height, mass)	Methodology (MVIC position and electrode site placement)	Hip extension exercises	Mean ± SD EMG excitation (%MVIC)	Quality Assessment
Worrell, Crisp, LaRosa [39]	Group 1: 6 males, 7 females (22 ± 8.6 years; 171 ± 15 cm; 69.1 ± 14.1 kg) Group 2: 13 males, 6 females (27.5 ± 5 years; 175 ± 9 cm; 73.3 ± 15.3 kg)	Prone hip extension against manual resistance at 0° of hip flexion. Placement half-way between the second sacral prominence and the greater trochanter of the femur.	Lateral step up (20 cm height)	20 ± 11 group 1 16 ± 7 group 2	11
Zeller, et al. [27]	9 males (20.3 ± 1 years; 182 ± 5 cm; 78.8 ± 4.0 kg) 9 females (22 ± 8.6 years; 170 ± 6 cm; 64.3 ± 5.5 kg)	Prone hip extension against manual resistance with knee flexed at 90° Placement not specified.	Single leg squat	62.7 ± 43 male 81.2 ± 28 female	11
Ayotte, et al. [24]	16 males, 7 females (31.2 ± 5.8 years; 173.1 ± 10.1 cm; 77.0 ± 13.9 kg)	Supine hip extension against fixed resistance pad placed proximal to the popliteal fossa from 30° hip flexion. Placement 1/3rd of the distance from the second sacral vertebra to the greater trochanter.	Forward step up (15.2 cm height) Lateral step up (15.2 cm height) Retro step up (15.2 cm height) Single leg mini squat (15.2 cm depth) Single leg wall squat, other leg knee extended	74 ± 43 56 ± 29 59 ± 35 57 ± 43 86 ± 43	14
Ekstrom, Donatelli, Carp [31]	19 males, 11 females (27 ± 8 years; 176 ± 8 cm; 74 ±11 kg)	Prone hip extension against manual resistance applied above the knee with knee flexed to 90° Placement between the lateral edge of the sacrum and the posterosuperior edge of the greater trochanter.	Bridge Lateral step up (20.3 cm height) Lunge Quadruped hip extension with arm raise Single leg bridge	25 ± 14 29 ± 13 36 ± 17 56.2 ± 22 40 ± 20	12
Ekstrom, Osborn, Hauer [40]	27 males, 32 females (age range 21-35 years)	Prone hip extension against manual resistance applied just above the knee with knee flexed at 90° Placement between the lateral edge of the sacrum and the posterosuperior edge of the greater trochanter.	Bridge Bridge with knees extended and feet on a swiss ball	27 ± 13 20 ± 14	11
Farrokhi, Pollard, Souza, et al. [41]	5 males, 5 females (26.7 ± 3.2 years)	Prone hip extension against strap resistance positioned superior to the knee joint with the knee flexed to 90° Placement midway between the second sacral vertebra and the greater trochanter.	Lunge Lunge with trunk extension Lunge with trunk flexion	18.5 ± 11.0 19.3 ± 11.8 22.3 ± 12.0	12
Boudreau, Dwyer, Mattacola, et al. [42]	22 males, 22 females (23.3 ± 5.1 years; 174.5 ± 9.1 cm; 74.6 ± 16.5 kg)	Standing hip extension against strap resistance placed around the distal third of the thigh with knee flexed to 90° Placement half the distance between the greater trochanter of the femur and the spinous process of the second sacral vertebra along an oblique angle at the level of the greater trochanter.	Forward step-up and over (20.3 cm height) Lunge Single leg squat	16.5 ± 11.7 21.7 ± 14.7 35.2 ± 24.0	14
Distefano, Blackburn, Marshall, et al. [43]	9 males, 12 females (22 ± 3 years; 171 ± 11 cm; 70.4 ± 15.3 kg)	Prone hip extension against manual resistance with knee flexed at 90° Placement 1/3rd of the distance between the second sacral vertebra and the greater trochanter.	Lunge Lateral lunge Transverse lunge Single leg deadlift Single leg squat	44 ± 23 41 ± 20 49 ± 20 59 ± 28 59 ± 27	12

Appendix 1. *Summary of all studies reviewed with EMG excitation (%MVIC) values given as the mean and the standard deviation. (n = 39) (continued)*

Author and date	Subjects (Sex, age, height, mass)	Methodology (MVIC position and electrode site placement)	Hi₍ extension exercises	Mean ± SD EMG excitation (%MVIC)	Quality Assessment
Lewis, Sahrmann [37]	11 females (27.7 ± 6.2 years; 165.2 ± 3.6 cm; 62.3 ± 6.9 kg)	Prone hip extension against manual resistance with knee flexed at 90° Placement on the muscle belly.	Prone hip extension from hip flexion of 30° Prone hip extension from hip flexion of 30° with verbal cues to activate the glutes Prone hip extension from hip flexion of 30° with verbal cues to activate the hamstrings	9.7 ± 2.9 21.6 ± 9.8 11.2 ± 5.2	12
Sakamoto, et al. [34]	16 males, 15 females (24.5 3.5 years; 170.0 ± 9.0 cm; 66.9 ± 11.9 kg	Prone hip extension against manual resistance with knee extension Placement 1/3rd of the distance between the second sacral vertebra and the greater trochanter.	Prone hip extension with knee extension Prone hip extension with 90° knee flexion Prone hip extension with lateral hip rotation and knee extension Prone hip extension with lateral hip rotation and knee flexion	12.7 ± 8.6 23.1 ± 21.2 22.5 ± 10.4 21.2 ± 12.0	12
Lubahn, Kernozek, Tyson, et al. [44]	18 females (22.3 ± 2.3 years; 166.82 ± 9.2 cm; 61.1 ± 7.1 kg)	Prone hip extension against manual resistance with the knee flexed at 90° Placement on the muscle belly.	Forward step up (Height unknown) Single leg squat Squat	36.4 ± 18.6 47.4 ± 21.2 21.7 ± 15.8	12
Boren, et al. [25]	24 (Anthropometrical details not provided)	Prone hip extension against a strap with the knee flexed at 90° Placement not specified.	Forward step up (20 cm height) Lateral step up (15 cm height) Plank with bent leg hip extension Skater squat Single leg bridge Single leg deadlift Single leg squat Quadruped bent leg hip extension DOM Quadruped bent leg hip extension non-DOM	54.7 63.8 106.2 66.2 54.2 58.8 70.7 59.7 21.0	10
Bouillon, Wilhelm, Eisel, et al. [45]	20 males, 20 females (22 ± 1 years; 170 ± 10 cm; 65 ± 13 kg)	Prone hip extension against manual resistance with the knee flexed at 90 ° Placement inferior and medial to a line drawn between the PSIS and the posterior greater trochanter.	Lateral lunge Lunge	12 ± 3 11 ± 2.5	12
Nakagawa, et al. [26]	20 males (23.5 ± 3.8 years; 176 ± 6.1 cm; 74.6 ± 9.1 kg) 20 females (21.8 ± 2.6 years; 163 ± 7.3 cm; 59.4 ± 7.3 kg)	Prone hip extension against strap with the knee flexed at 90° Placement parallel to the mid–muscle belly.	Single leg squat	24.6 ± 2.7 females 18.9 ± 8.9 males	12
Tateuchi, Taniguchi, Mori, et al. [46]	10 males, 6 females (24.3 ± 5.2 years; 165.7 ± 7.9 cm; 59.0 ± 8.0 kg)	Prone hip extension against manual resistance. Placement halfway on the line extending between the sacrum and greater trochanter.	Prone hip extension from 30° hip flexion to 10° hip extension	10.9 ± 3.3	10
De Ridder et al. [47]	8 males, 6 females (24.7 ± 3.2 years; 172.9 ± 6.4 cm; 64.5 ± 12.5 kg)	Prone hip extension against manual resistance with the knee flexed at 90° Placement midway between the posterosuperior iliac spine and the ischial tuberosity.	Prone back/torso extension Reverse hyperextension	44.9 concentric 33.1 eccentric 30.3 concentric 20.3 eccentric	12

Appendix 1. *Summary of all studies reviewed with EMG excitation (%MVIC) values given as the mean and the standard deviation. (n = 39) (continued)*

Author and date	Subjects (Sex, age, height, mass)	Methodology (MVIC position and electrode site placement)	Hip extension exercises	Mean ± SD EMG excitation (%MVIC)	Quality Assessment
Kang, et al. [8]	18 males, 12 females (22.8 ± 2.9 years; 170.3 ± 4.1 cm; 66.9 ± 10.8 kg)	Prone hip extension against manual resistance with the knee flexed at 90° Placement halfway between the greater trochanter and second sacral vertebra in the middle of the muscle and at an oblique angle.	Prone hip extension with knee flexion with hip abducted 0° Prone hip extension with knee flexion with hip abducted 15° Prone hip extension with knee flexion with hip abducted 30°	20.2 ± 8.6 23.4 ± 9.9 29.6 ± 11.5	11
Lee, Ko, Lim [48]	20 males (22.9 ± 2.1 years; 174.4 ± 3.9 cm; 70.0 ± 6.2 kg)	Side-lying hip abduction against strap resistance with the hip in 90° abduction. Placement 1/3rd of the distance between the second sacral vertebra and the greater trochanter.	Lunge Lunge with compression pelvic belt Single leg deadlift Single leg deadlift with compression pelvic belt Single leg squat Single leg squat with compression pelvic belt	11.5 ± 6.9 13.9 ± 7.7 27.9 ± 18.4 36.3 ± 21.9 30.5 ± 19.4 35.5 ± 21.7	12
Webster, Gribble [49]	1 male, 8 females (22.9 ± 4.5 years; 164 ± 6.5 cm; 65.4 ± 10 kg)	Prone hip extension against manual resistance with the knee flexed at 90° Placement half-way between the second sacral prominence and the greater trochanter of the femur.	Single leg squat with rotation Transverse lunge	78 ± 45 58 ± 3	12
Bolgla, et al. [28]	18 males (24.3 ± 3.4 years; 180 ± 10 cm; 81.2 ± 9.7 kg) 16 females (24.0 ± 1.5 years; 165 ± 10 cm; 59.9 ± 8.8 kg)	Prone hip extension against strap with the knee flexed at 90° Placement parallel alignment over the belly.	Single leg wall slide, other leg knee flexed Single leg mini-squat Lateral step down (20 cm height) Forward step down (20 cm height)	21.6 male 32.0 female 20.3 male 26.6 female 8.4 male 24.6 female 19.0 male 27.2 female	12
Hollman, Galardi, Lin, et al. [50]	41 females (18-36 years)	Prone hip extension against strap with the knee flexed at 90° Placement at one-half the distance between the sacrum and greater trochanter.	Single leg squat	20.9-23.8	11
Emami, Arab, Ghamkhar [51]	10 males (22.5 ± 3.8 years; 177 ± 7 cm; 74.1 ± 8.0 kg)	Prone hip extension against manual resistance with the knee flexed at 90° Placement at the midpoint of a line running from S2 to the greater trochanter.	Prone hip extension with knee extension	18.3 ± 12.1	12
MacAskill, Durant, Wallace [52]	14 males, 20 females (21.5 ± 1.7 years; 170.5 ± 11 cm; 67.6 ± 7.5 kg)	Prone hip extension against manual resistance with the knee flexed at 90° Placement 1/3rd of the distance between the second sacral vertebra and the greater trochanter.	Forward step up (15 cm height) Lateral step up (15 cm height)	28.7 ± 18.7 31 ± 19.9	11
Park, Yoo [53]	18 males (21.9 ± 2.2 years; 175.1 ± 5.3 cm; 66.6 ± 8.4 kg)	Prone hip extension against manual resistance with the knee flexed at 90° Placement at half the distance between the trochanter and the sacral vertebrae in the middle of the muscle on an oblique angle.	Back/torso extension with extended knees and hands across chest Back/torso extension with extended knees and hands behind head Back/torso extension with flexed knees 90° and hands across chest Back/torso extension with flexed knees 90° and hands behind head	28.3 ± 14.5 26.5 ± 13.6 34.8 ± 20.6 36.6 ± 22.6	11

Appendix 1. *Summary of all studies reviewed with EMG excitation (%MVIC) values given as the mean and the standard deviation. (n = 39) (continued)*

Author and date	Subjects (Sex, age, height, mass)	Methodology (MVIC position and electrode site placement)	Hip extension exercises	Mean ± SD EMG excitation (%MVIC)	Quality Assessment
Suehiro, et al. [32]	21 males (20.2 ± 0.4 years; 171.1 ± 5.0 cm; 64.3 ± 10.5 kg)	Prone hip extension against manual resistance with the knee flexed at 90° Placement halfway between the greater trochanter and the second sacral vertebra.	Prone hip extension with 90 ° knee flexion and neutral hip position Prone hip extension with 90 ° knee flexion and 15° hip abduction Prone hip extension with 90 ° knee flexion and 15° hip abduction and 20° hip external rotation	14.1 ± 9.4 22.5± 13.6 41.0 ± 23.6	11
Kim, Kim [54]	14 males, 16 females (24.7 ± 3.2 years; 167.5 ± 8.2 cm; 61.5 ± 6.9 kg)	Prone hip extension against manual resistance with the knee flexed at 90° Placement 1/3rd the distance between the second sacral vertebrae and the greater trochanter.	Prone hip extension to 10° Prone hip extension to 10° with abdominal drawing-in Prone hip extension to 10° with pelvic tilt > 15° Prone hip extension to 10° with abdominal drawing-in with pelvic tilt > 15°	23.9 ± 18.5 24.4 ± 14.3 32.5 ± 21.3 45.9 ±33.7	11
Kim, Yoo [36]	18 males (23.3 ± 1.8 years; 177.4 ± 5.3 cm; 74.2 ± 7.2 kg)	Prone hip extension against manual resistance with the knee flexed at 90° Placement not specified.	Prone hip extension with upper body on table Prone hip extension with body on floor	62.3 ± 27.1 56.5 ± 20.2	11
Mills, Frank, Goto, et al. [55]	20 females (Anthropometrical details not provided)	Prone hip extension against manual resistance with the knee flexed at 90° Placement 1/3rd the distance between the second sacral vertebrae and the greater trochanter	Squat	12.4 ± 6.3	11
Yoon, Lee, An [33]	15 subjects (26.7 ± 3.7 years; 167.1 ± 9.2 cm; 58.1 ± 11.7 kg)	MVIC position not specified Placement not specified	Prone hip extension from 0° hip flexion Prone hip extension from 15° hip flexion Prone hip extension from 30° hip flexion	19.7 ± 7.9 22.5 ± 9.4 18.9 ± 7.8	11
Youdas, Hartman, Murphy, et al. [56]	13 males (23.4 ± 1.3 years; 180 ± 10 cm; 79.7 ± 10.6 kg) 13 females (23.5 ± 1.2 years; 170 ± 10 cm; 63.7 ± 7.4 kg)	Prone hip extension against manual resistance with the knee flexed at 90° Placement on the muscle belly, parallel to the line of action.	Bridge Bridge with feet on swiss ball Single leg bridge Single leg bridge with foot on bosu Bridge with hamstring curl Bridge with feet on swiss ball and hamstring curl	16.4 13.0 32.6 28.4 18.5 10.9	12
Choi, Bak, Cho, et al. [57]	14 males, 13 females (27.8 ± 5.8 years; 166.4 ± 10.1 cm; 66.2 ± 13.4 kg)	MVIC position not specified Placement between the sacrum and greater trochanter	Bridge Single leg bridge Single leg bridge (raised leg abducted to 30°)	41.5 ± 16.4 47.3 ± 16.0 46.7 ± 12.0	11
Jeon, et al. [35]	16 males (25.4 ± 4.2 years; 174.7 ± 2.8 cm; 73.1 ± 2.1 kg)	Prone hip extension against manual resistance with the knee flexed at 90° Placement at the midpoint of the line extending between the greater trochanter and sacrum	Prone hip extension with upper body on table Prone hip extension with upper body on table and abdominals drawing-in Prone hip extension with upper body on table and flexed contralateral knee joint on a chair	43.9 ± 16.1 47.5 ± 19.8 66.4 ± 25.8	12
Lee, Song, Kwon [58]	10 males, 10 females (21.1 ± 1.8 years; 168.7 ± 8.3 cm; 66.1 ± 12.3 kg)	MVIC method not specified. Placement at 50% on the line between the sacral vertebrae and the greater trochanter	Squat with 0° trunk flexion Squat with 15° trunk flexion Squat with 30° trunk flexion	6.1 ± 4.0 6.3 ± 4.0 8.0 ± 4.9	11

Appendix 1. *Summary of all studies reviewed with EMG excitation (%MVIC) values given as the mean and the standard deviation. (n = 39) (continued)*

Author and date	Subjects (Sex, age, height, mass)	Methodology (MVIC position and electrode site placement)	Hip extension exercises	Mean ± SD EMG excitation (%MVIC)	Quality Assessment
Selkowitz, Beneck, Powers [19]	10 males, 10 females (27.9 ± 6.2 years; 170.5 ± 11.1 cm; 67.7 ± 14.1 kg)	Four conditions normalised to whichever contraction elicited greater EMG excitation: 1) Prone hip extension of 45° with the knee flexed at 90° against strap resistance. 2) Prone hip extension of 0° with the knee flexed at 90° against strap resistance. 3) Sidelying position with hip in 30° abduction and knee extended against strap. 4) As position 3 with hip in 45° flexion. Placement Gmax (S) inserted superior and lateral to the midpoint of a line drawn between the posterior superior iliac spine and the posterior greater trochanter, Gmax (I) inserted inferior and medial to the midpoint of the same line, such that it was 2.5 to 5.0 cm above the gluteal fold.	Bridge Forward step up Lunge Single leg bridge Squat Quadruped hip extension with knee extended Quadruped hip extension with knee flexed	17.4 ± 12.0 (S) 22.3 ± 10.1 (I) 22.8 ± 15.6 (S) 15.7 ± 6.0 (I) 20.1 ± 11.1 (S) 18.5 ± 6.2 (I) 34.6 ± 16.8 (S) 36.7 ± 10.0 (I) 12.9 ± 7.9 (S) 10.5 ± 7.1 (I) 28.5 ± 16.6 (S) 31.2 ± 16.5(I) 30.1 ± 12.5 (S) 34.3 ± 16.3 (I)	12
Chan, et al. [20]	10 males, 10 females (21.1 ± 1.7 years; 166.8 ± 7.9 cm; 58.1 ± 9.2 kg)	Prone hip extension against manual resistance with the knee flexed at 90° Placement 1/3rd of the distance from iliac crest to greater trochanter, starting from greater trochanter.	Prone hip extension up to 20° with 90 ° knee flexion Prone hip extension up to 20° with 90 ° knee flexion with abdominal bracing	14.8 concentric (S) 12.3 eccentric (S) 20.1 concentric (I) 11.7 eccentric (I) 19.7 concentric (S) 16.6 eccentric (S) 25.6 concentric (I) 36.0 eccentric (I)	12
Hollman, et al. [29]	15 females (23.3 ± 1.7 years; 169.4 ± 8.3 cm; 62.6 ± 6.7 kg)	Prone hip extension against strap resistance with the knee flexed at 90° Placement halfway between the sacral vertebrae and the greater trochanter	Bridge Bridge with verbal and tactile cueing	16.8 33.0	13
Lehecka, et al. [30]	12 males, 16 females (23.4 ± 2.3 years; 173 ± 11 cm; 72.6 ± 13.9 kg)	Prone hip extension against strap resistance with the knee flexed at 90° Placement anterosuperior to Gmax, inferior to the lateral aspect of the iliac crest on a line towards the greater trochanter on the muscle belly.	Single leg bridge. DOM leg 90° knee flexion with foot flat. Non-DOM leg knee extended Single leg bridge. DOM leg 135° knee flexion with foot flat. Non-DOM leg knee extended Single leg bridge. DOM leg 90° knee flexion with foot flat. Non-DOM leg knee relaxed in flexion and femur vertical Single leg bridge. DOM leg 90° knee flexion with dorsiflexed ankle. Non-DOM leg knee relaxed in flexion and femur vertical Single leg bridge. DOM leg 135° knee flexion with dorsiflexed ankle. Non-DOM leg knee relaxed in flexion and femur vertical	51.0 ± 28.1 47.4 ± 24.8 47.2 ± 28.1 49.1 ± 26.4 40.4 ± 24.6	11

Appendix 1. *Summary of all studies reviewed with EMG excitation (%MVIC) values given as the mean and the standard deviation. (n = 39) (continued)*

Author and date	Subjects (Sex, age, height, mass)	Methodology (MVIC position and electrode site placement)	Hi⸱ extension exercises	Mean ± SD EMG excitation (%MVIC)	Quality Assessment
Van Oosterwijck, et al. [38]	4 males, 9 females (22.6 ± 2.1 years; 172 ± 7.3 cm; 61.3 ± 9.5 kg)	Prone hip extension against manual resistance with the knee flexed at 90° Placement midway between the posterosuperior iliac spine and the ischial tuberosity).	Prone back/torso extension without lumbopelvic control strategy Prone back/torso extension with lumbopelvic control strategy Reverse hyperextension without lumbopelvic control strategy Reverse hyperextension with lumbopelvic control strategy	23.8 ± 10.1 32.4 ± 21.6 22.0 ± 7.7 38.8 ± 24.1	12
Youdas, et al. [2]	13 males, 13 females (23.5 ± 1.2 years; 175.0 ± 10.0 cm; 71.7 ± 9.0 kg)	Prone hip extension against manual resistance with the knee flexed at 90° Placement parallel to the muscle's line of action.	Single leg bridge Supine manual resisted hip extension	33.8 34.7	12

BM = body mass, DOM = dominant, EMG = electromyography, **Gmax** = Gluteus Maximus, I = inferior, MVIC = maximum voluntary isometric contraction, ROM = range of motion, S = superior