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SYSTEMATIC REVIEW/META ANALYSIS

A SYSTEMATIC REVIEW AND META-ANALYSIS OF COMMON THERAPEUTIC EXERCISES THAT GENERATE HIGHEST MUSCLE ACTIVITY IN THE GLUTEUS MEDIUS AND GLUTEUS MINIMUS SEGMENTS

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ABSTRACT

Background: The gluteus medius (GMed) and gluteus minimus (GMin) muscle segments demonstrate different responses to pathology and ageing, hence it is important in rehabilitation that prescribed therapeutic exercises can effectively target the individual segments with adequate exercise intensity for strengthening.

Purpose: The purpose of this systematic review was to evaluate whether common therapeutic exercises generate at least high (> 40% maximum voluntary isometric contraction (MVIC)) electromyographic (EMG) activity in the GMed (anterior, middle and posterior) and GMin (anterior and posterior) segments.

Methods: Seven databases (MEDLINE, EMBASE, CINAHL, AusSPORT, PEDro, SPORTdiscus and Cochrane Library) were searched from inception to May 2018 for terms relating to gluteal muscle, exercise, and EMG. The search yielded 6918 records with 56 suitable for inclusion. Quality assessment, data extraction and data analysis were then undertaken with exercise data pooled into a meta-analysis where two or more studies were available for an exercise and muscle segment.

Results: For the GMed, different variations of the hip hitch/ pelvic drop exercise generated at least high activity in all segments. The dip test, and isometric standing hip abduction are other options to target the anterior GMed segment, while isometric standing hip abduction can be used for the posterior GMed segment. For the middle GMed segment, the single leg bridge; side-lying hip abduction with hip internal rotation; lateral step-up; standing hip abduction on stance or swing leg with added resistance; and resisted side-step were the best options for generating at least high activity. Standing isometric hip abduction and different variations of the hip hitch/ pelvic drop exercise generated at least high activity in all GMin segments, while side-lying hip abduction, the dip test, single leg bridge and single leg squat can also be used for targeting the posterior GMin segment.

Conclusion: The findings from this review provide the clinician with confidence in exercise prescription for targeting individual GMed and GMin segments for potential strengthening following injury or ageing.

Level of Evidence: Level 1.

What is known about the subject: Previous reviews on GMed exercises have been based on single electrode, surface EMG measures at middle GMed segment. It is not known whether these exercises effectively target the other segments of GMed or the GMin at a sufficient intensity for strengthening.

What this study adds to existing knowledge: This review provides the clinician with confidence in exercise prescription of common therapeutic exercises to effectively target individual GMed and GMin segments for potential strengthening.

Keywords: EMG, gluteal muscle, hip, exercise therapy, movement system

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INTRODUCTION

Gluteal muscle dysfunction is associated with pain and symptoms at the ankle,[1-3] knee,[4-6] hip,[7-9] and lower back.[10,11] There is also evidence that severity of symptoms on clinical presentation is associated with atrophied or weak muscles.[12,13] It is therefore important to understand the most effective methods of activating the gluteal muscles with therapeutic exercise for the purpose of strengthening these muscles in clinical populations.[14-16]

The effectiveness of hip strengthening programs for improving symptoms and quality of life in clinical conditions is variable. While there are clear benefits of hip strengthening exercises for conditions of the knee,[17] results for conditions such as hip osteoarthritis are less convincing with only mild benefits in the short term.[18] Two reasons that may account for variable effects are; (1) the exercises used in typical rehabilitation programs may not activate the muscles with sufficient intensity to elicit strength and/or hypertrophic adaptations, or (2) the exercises typically prescribed may not target individual segments of gluteus medius (GMed) and gluteus minimus (GMin) and/or with sufficient intensity. These muscles consist of distinct individual segments (anterior, middle and posterior for GMed; and anterior and posterior for GMin) with separate innervations, different muscle fiber orientations, and diverse functional roles.[19-21] In addition to generalized muscle atrophy of GMin and GMed in clinical presentations such as hip osteoarthritis,[22] gluteal tendinopathy,[23] and following total hip replacement,[24,25] there is evidence of specific segmental atrophy and dysfunction.[24-26] Understanding the role of exercises for targeting individual muscle segments of GMin and GMed may enable better tailoring of exercise interventions to people with varied underlying presentations, or those for specific conditions.

There are a number of reviews[27-31] that have reported GMed activity levels for various therapeutic exercises but have mostly contained studies that utilize a single surface electrode positioned over the middle GMed segment to record electromyographic (EMG) activity. No previous reviews have considered exercises to target the individual segments of the GMed, and none have examined therapeutic exercises for the GMin. An updated systematic review will inform clinicians of the effectiveness of exercises targeting individual GMed and GMin segments.

The purpose of this systematic review was to evaluate whether common therapeutic exercises generate at least high (> 40% maximum voluntary isometric contraction (MVIC)) electromyographic (EMG) activity in the GMed (anterior, middle and posterior) and GMin (anterior and posterior) segments.

METHODS

Search strategy

This review was conducted in accordance with PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-analyses) statement guidelines[32] A systematic literature search was conducted of MEDLINE, CINAHL, EMBASE, AUSPORT, SPORTDiscus, PEDRO and the Cochrane Library from inception to first week May 2018. These databases were searched using free-text words, keywords mapped to medical subject headings (MeSH), and filters were applied for human subjects where possible. Boolean operators were used to combine the key words with truncated search terms: (glut* OR buttock* OR hip rotat* OR hip abduct*) AND (strength* OR contract* OR electromyo* OR EMG OR electrode* OR activ* OR intensit* OR peak amplitude* OR funct*)

Further relevant studies were searched through reference scanning of included full-text studies.

From the initial search yield, articles were imported into Endnote version X8, duplicate papers were removed, and the abstracts and titles of the remaining papers were screened by two reviewers (DM and TP) independently through application of the inclusion and exclusion criteria. Full-text was obtained for the remaining studies to determine eligibility for inclusion into the review through consultation and consensus between the reviewers (DM and TP).

Inclusion and Exclusion Criteria

Inclusion and exclusion criteria were determined prior to administering the search strategy. Since most studies in this area of research are either cross-sectional or single-group pre- and post-test design, all study designs were eligible for inclusion except clinical commentary or opinion articles, and unpublished material such as theses, abstracts, and conference proceedings.

Studies comprising of only healthy participants were included in this review. A study with pathological participants was only included if there was a group of healthy controls with separate data presented.

Normalized muscle activity measured using surface or intramuscular EMG was selected as the outcome measure of interest since it has been long established and universally advocated as the method of choice in measuring and comparing muscle activity between different exercises and individuals.[33-36] To be included, studies had to normalize EMG to a MVIC since this has been found to be the most reliable method for comparing exercises for the GMed in healthy participants[37] and is clinically interpretable. This also allows a more meaningful comparison between studies and a logical synthesis of findings.

Due to the vast breadth of studies that have evaluated exercises for the GMed, only studies that evaluated the GMed and / or the GMin, and contained at least one commonly evaluated therapeutic exercise (including squats, lunges, steps, hip hitches, standing hip abduction, supine bridges, side lie hip abduction and side lie hip clam) and the different variations of these exercises were accepted into this review. Exercises using custom-made devices or commercial gym equipment were excluded from this review as were plyometric exercise activities such as hopping, running or jumping.

Quality assessment

Methodological quality of included studies in this review were assessed independently by two reviewers (DM and TP) using a standardized quality assessment tool recommended by the Non-Randomized Studies Group of the Cochrane Collaboration and previously adapted for EMG study reviews.[38,39] With the scope of the tool covering external validity, performance bias and detection bias, these items are then displayed in its raw form individually for the reader to evaluate the study quality for each item rather than be determined by an overall summary score.

Data extraction

Data were extracted by one reviewer (DM) and verified by a second (TP) using a standardized form[40] that was modified for this review. The main study characteristics extracted included; participant characteristics; electrode placement; normalisation method; exercise characteristics; and study results. Where studies had healthy and pathological participants performing therapeutic exercises, data were extracted for the healthy participants. Data relating to muscle activity for each exercise was summarized as mean % MVIC with 95% confidence interval (CI). Data reported as medians and inter-quartile range (IQR) were converted to means and standard deviations (SD) using methods described by Wan, et al.[41] The meta (v 4.9-5) R statistical software package was used to convert the SD to a 95% CI. Calculations were performed in the log scale and backtransformed to raw units (% MVIC) for ease of interpretation. Electromyographical technical data for collection, processing and analysis were also extracted from all the included studies since collection, normalisation and processing methods can influence muscle activity profiles.[42]

Data analysis

Data were grouped according to muscle segment and exercise and summarised qualitatively according to level of activity. Where two or more studies were available for a specific muscle segment and exercise, data were pooled quantitatively in a meta-analysis using the meta package in R. A random effects model was used for data pooling, and statistical heterogeneity was described using the I^2 statistic (0-100%) where 25%, 50% or 75% was considered low, moderate or high level of heterogeneity respectively.[43]

For simplicity in analyzing the exercises for activation levels across the studies, exercise results were characterized into very-high (>60% MVIC), high (41-60% MVIC), moderate (21-40% MVIC) or low (0-20% MVIC) levels of activation as has been utilized in previous reviews.[28,31,44]

RESULTS

Study selection

The flow of studies through the review is illustrated in Figure 1. Fifty-six studies satisfied the eligibility criteria and were included in this review.

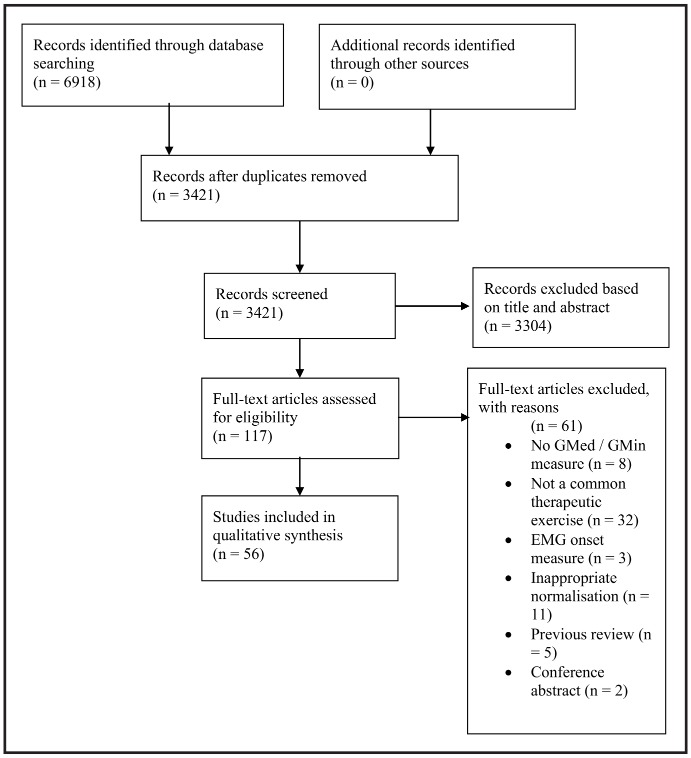

Figure 1. *PRISMA diagram of study selection through the review.*

Methodological quality

The risk of bias across studies is summarized in Table 1. All but four studies provided adequate demographic data for the study population and only one study had a blinded data analyst for raw EMG data[45] (Table 1). Eighteen studies provided insufficient information on appropriate electrode positioning and 14 studies did not randomize the exercise protocol in order to minimize the potential for bias as a result of learning effects and fatigue (Table 1).

Study characteristics

The 56 included studies for this review are summarized in Tables 2 and 3. There were 55 studies included for GMed and two studies[46,47] for GMin with one study[46] evaluating both GMed and GMin. All the studies were cross-sectional with six including a comparison group.[5,48-52] These comparison groups included a specific lower limb pathology (including patellofemoral pain, chronic ankle instability, hip osteoarthritis and anterior cruciate ligament reconstruction) or various orthotic conditions. Sample sizes of the included studies ranged from six to 44 participants. Most studies contained a mixture of men and women aged 20-30 years with 13 studies[5,46,52-62] comprising a single gender population, and one study[46] recruiting healthy elderly participants.

A single surface electrode positioned at the middle segment of GMed on the dominant limb was used in most GMed studies with six different electrode positions described (Table 2). Five studies[46,52,55,62,63] recorded EMG measurements for the anterior, middle and posterior segments of GMed with only one study[46] using fine wire electrodes. Two studies[46,47] recorded the anterior and posterior segments of GMin using fine wire electrodes.

Normalization of the EMG signal was typically performed with side-lying hip abduction MVIC for GMed (Table 2). Standing hip abduction[48,63-67] was used in other studies, while one study[48] used an isometric single leg wall squat in a custom-made apparatus to determine MVIC. Two studies[46,63] for GMed and two studies[46,47] for GMin determined each segments' maximum value from performing MVICs for different hip actions.

Therapeutic exercise characteristics were diverse across the included studies (Tables 2 and 3). All included studies attempted to standardize exercise performance and control EMG signal variability between participants by employing strategies such as allowing practice repetitions before testing; controlling exercise ROM; and using a metronome to control contraction speed (Tables 2 and 3). For most studies, the potential impact of fatigue was minimized by randomizing the exercise order; having rest periods between exercises and trials; and restricting numbers of trials (Tables 2 and 3).

Only two studies[49,65] reported on all technical parameters for collection, processing and analysis of the EMG signal (Table 4).

Non-weight bearing exercises

Side-lying hip abduction

Gluteus medius

Side-lying hip abduction was the most commonly investigated exercise in the non-weight bearing position for GMed.[56,58,66,68-79] Moderate mean activity levels (40.10 (95% CI (33.37, 48.21)) % MVIC) were generated for middle GMed when the results were

Table 1. *Methodological quality of the included studies using a risk of bias assessment.*

Study	External validity	Internal validity				
		Detection	Selection bias / control of confounding			
	Representative	Blinded assessors	Appropriate electrode positioning	Randomisation of exercises	Appropriate normalisation procedure	Appropriate statistical tests used to assess EMG activity
Ayotte et al. (2007)	✓	×	×	✓	✓	✓
Barton et al. (2013)	✓	×	✓	✓	✓	✓
Berry et al. (2015)	✓	×	✓	✓	✓	✓
Bolgla et al. (2014)	✓	×	✓	✓	✓	✓
Bolgla et al. (2016)	✓	×	✓	✓	✓	✓
Bolgla & Uhl (2005)	✓	×	✓	✓	✓	✓
Boren et al. (2011)	×	×	✓	✓	✓	×
Boudreau et al. (2009)	✓	×	✓	✓	✓	✓
Bouillon et al. (2012)	✓	×	✓	✓	✓	✓
Cambridge et al. (2012)	✓	×	×	✓	✓	✓
Chan et al. (2017)	✓	×	×	✓	✓	✓
Cynn et al. (2006)	✓	×	✓	×	✓	✓
Distefano et al. (2009)	✓	×	×	✓	✓	✓
Dwyer et al. (2010)	✓	×	✓	✓	✓	✓
Dwyer et al. (2016)	✓	×	✓	✓	✓	✓
Ekstrom et al. (2007)	✓	×	✓	✓	✓	✓
Felecio et al. (2011)	✓	×	✓	✓	✓	✓
Ganderton et al. (2017)	✓	×	✓	✓	✓	✓
Harput et al. (2016)	✓	×	✓	×	✓	✓
Hatfield et al. (2016)	✓	×	✓	✓	✓	✓
Heo et al. (2013)	✓	×	×	×	×	✓
Hertel et al. (2005)	✓	×	×	✓	✓	✓
Ju & Yoo (2017)	✓	×	×	×	✓	✓
Ju & Yoo (2016)	✓	×	✓	×	✓	✓
Kang et al. (2014)	✓	×	✓	×	✓	×
Kim et al. (2015)	✓	×	×	×	✓	✓
Krause et al. (2018)	✓	×	✓	✓	✓	✓
Krause et al. (2009)	✓	×	×	✓	✓	✓
Lee et al. (2013)	✓	×	×	✓	✓	✓
Lee et al. (2014)	✓	×	✓	✓	✓	✓
Lehecka et al. (2017)	✓	✓	✓	✓	✓	✓
Lin et al. (2016)	✓	×	×	×	✓	✓
Lubahn et al. (2011)	✓	×	✓	✓	✓	✓
MacAskill et al. (2014)	✓	×	×	✓	✓	✓
Mauntel et al. (2013)	✓	×	×	✓	✓	✓
McBeth et al. (2013)	✓	×	✓	×	✓	✓
Monteiro et al. (2017)	✓	×	✓	✓	✓	✓
Moore et al. (2018)	✓	×	✓	✓	✓	✓

pooled for 8 studies (Figure 2) (Table 5). The addition of external resistance further increased activity levels to very high, although there was a high degree of heterogeneity (I^2 = 95%).

High mean GMed middle activity levels were generated by hip abduction with internal rotation (44.73 [32.99, 60.65] % MVIC), while moderate activity levels were elicited for hip abduction with

Table 1. *Methodological quality of the included studies using a risk of bias assessment. (continuie)*

Morimoto et al. (2018)	×	×	×	×	✓	✓
Noh et al. (2012)	✓	×	✓	✓	✓	✓
Oliver & Stone (2016)	×	×	✓	×	✓	✓
Oliver et al. (2010)	×	×	✓	✓	✓	✓
O'Sullivan et al. (2012)	✓	×	✓	×	✓	✓
O'Sullivan et al. (2010)	✓	×	✓	✓	✓	✓
Petrofsky et al. (2005)	✓	×	×	×	✓	✓
Philippon et al. (2011)	✓	×	×	✓	✓	✓
Selkowitz et al. (2013)	✓	×	✓	✓	✓	✓
Sidorkewicz et al. (2014)	✓	×	✓	✓	✓	✓
Sinsurin et al. (2015)	✓	×	✓	✓	✓	✓
Souza & Powers (2009)	✓	×	✓	✓	✓	✓
Webster & Gribble (2013)	✓	×	✓	✓	✓	✓
Willcox & Burden (2013)	✓	×	×	✓	✓	✓
Youdas et al. (2014)	✓	×	✓	✓	✓	✓
Youdas et al. (2015)	✓	×	✓	✓	✓	✓
Youdas et al. (2013)	✓	×	✓	×	✓	✓
Zeller et al. (2003)	✓	×	✓	✓	✓	✓

Note:✓ indicates the quality measure was addressed adequately, × indicates the quality measure was not addressed adequately or not reported clearly in the study
Representative: ✓ if the study describes demographic details (age, gender, height, weight).
Blinded assessors: ✓ if data assessed or processed by a blinded assessor.
Appropriate electrode positioning: ✓ if surface electrodes were described being placed according to SENIAM guidelines or anatomy atlas.
Appropriate normalisation procedure:✓ if procedure described tested position and contraction type.

external rotation (38.01 [29.54, 48.91] % MVIC)[66,75,76,79] (Figure 2).

Gluteus minimus

One study[47] evaluated GMin activity for side-lying abduction and found moderate activity (38% MVIC) for the anterior segment and high activity (44% MVIC) for the posterior segment (Figures 3 and 4) (Table 6).

Side-lying hip clam

Gluteus medius

The side-lying hip clam was evaluated in 10 studies[46,58,66,68-70,73,78,80,81] with varying positions of hip flexion. Low to moderate activity levels (17-28% MVIC) were reported across the studies for middle GMed (Figure 3) (Table 5). There were wide variations between studies for exercise technique; angle of hip and knee flexion; repetitions; and use of external loading. One study[46] recorded segmental GMed activity levels using fine wire EMG and found low activity levels for the anterior (3% MVIC) and middle segments (13% MVIC), and moderate activity (23% MVIC) for the posterior segment. Altering the angle of hip flexion or trunk position had minimal effect on mean GMed activity levels generated for this exercise[80] (Figure 3).

Gluteus minimus

Two studies[46,47] evaluated segmental activity levels for GMin. When pooled together, low activity was recorded for anterior (4.53 (95% CI (1.88, 10.89))% MVIC) and posterior (12.22 (5.09, 29.35)% MVIC) segments (Figures 3 and 4) (Table 6).

Standing hip abduction (open chain)

Gluteus medius

Standing hip abduction on the swing leg was evaluated in three studies[59,72,82] (Table 5). Two studies had added external resistance and could be pooled together generating high middle GMed activity levels (42.95 [95% CI 27.14, 67.99] % MVIC) (Figure 7). There was however a high degree of heterogeneity (I^2 = 84%). The one study[59] without added resistance recorded very high activity levels (64% MVIC).

Table 2. *Summary of included gluteus medius studies.*

Study and type	Participant characteristics	EMG electrode type and placement	Normalisation method	Exercise characteristics	Results (% MVIC (SD))
Ayotte et al. (2007) (Cross-sectional)	23 (16 M) physically active Department of Defence. 31.2 (5.8) years; 173.1 (10.1) cm; 77 (13.9) kg.	Surface (33% iliac crest to greater trochanter) dominant limb.	MVIC 3 trials x 3 secs in side-lie 0^0 abd., neutral flex. / ext. 1 min rest between trials.	Exercises – 5 randomised: wall squat; mini squat; forward step-up; lateral step-up; retro step-up. Repetitions – 3 of 1.5 secs concentric and 1.5 secs eccentric to a metronome (40 bpm). Practice reps before. Rest – 5 mins between MVIC testing and exs.	wall squat 52 (22); forward step-up 44 (17); lateral step-up 38 (18); retro step-up 37 (18); mini squat 36 (17).
Barton et al. (2013) (Cross-sectional)	19 (11 M) healthy university. 28.4 (2.7) years; 172.4 (5.8) cm; 67.8 (10.4) kg.	Surface[105] on dominant limb.	MVIC 3 trials x 5 sec in side-lie 10^0 abd, neutral hip flex. - ext. 1 min rest between reps.	Exercises – 4 randomised: wall squat; wall squat against gym ball; SL squat with contralateral leg wall support; SL squat with contralateral leg against gym ball wall support. Repetitions – 3 trials, 2 secs eccentric, 5 secs isometric, 2 secs concentric. 1 practice trial before. Rest - 30 secs between trials.	SL squat with ball 46 (15); SL squat 42 (12); squat with ball 10 (7); squat 9 (5).
Berry et al. (2015) (Cross-sectional)	24 (12 M) healthy college. 22.9 (2.9) years; 171.1 (10.5) cm; 68.6 (12.9) kg	Surface[106] post. portion bilaterally.	MVIC 1 trial x 3 secs in side-lie abd. 1 practice rep before.	Exercises – 2 randomised: side-step upright posture with elastic resistance; side-step squat posture with elastic resistance. Repetitions – 8 for each ex. for each direction.	squat posture stance limb 35.7 (13.8); squat posture moving limb 23.3 (11.2); upright posture stance limb 22.9 (9.5); upright posture moving limb 18.7 (8.0).
Bolgla et al. (2016) (Cross-sectional)	34 (18 M) healthy active university. 24.3 (3.4) years (M), 24 (1.5) years (F); 1.8 (0.1) m (M), 1.65 (0.1) m (F); 81.2 (9.7) kg (M), 59.9 (8.8) kg (F).	Surface (33% iliac crest to greater trochanter) on dominant limb.	MVIC 2 trials x 5 sec in side-lie abd. 1 practice trial before. 30 secs rest between trials.	Exercises – 4 randomised: SL wall squat; SL mini squat; lateral step down; forward step down. Repetitions – 15 to a metronome (40 bpm), 1 beat down, 1 beat up, 1 beat rest. Practice reps before. Rest – 3 mins between exs.	SL wall squat 26.5 (12); SL mini squat 23.2 (12.2); front step down 22.8 (12.2); lateral step down 21.4 (10.7).
Bolgla et al. (2014) (Cross-sectional)	34 (18M) healthy active university. 24.3 (3.4) years (M), 24 (1.5) years (F); 1.8 (0.1) m (M), 1.65 (0.1) m (F); 81.2 (9.7) kg (M), 59.9 (8.8) kg (F).	Surface on dominant limb.	MVIC 2 trials x 5 sec in side-lie abd	Exercises – 4 randomised: SL wall squat; SL mini squat; lateral step down; forward step down. Repetitions – 15 to a metronome (40 bpm). Rest – 3 mins between exs.	SL wall squat 21.6 (8.6) (M), 32 (13.1) (F); SL mini squat 20.3 (11.2) (M), 26.6 (12.8) (F); front step down 19 (9.2) (M), 27.2 (13.9) (F); lateral step down 18.5 (10.2) (M), 24.6 (10.6) (F).
Bolgla and Uhl (2005) (Cross-sectional)	16 (8 M) healthy university. 27 (5) years; 1.7 (0.2) m; 76 (15) kg.	Surface (33% iliac crest to greater trochanter) on (R) limb.	MVIC 3 trials x 3-5 secs in side-lie 25^0 abd. 1 min rest between trials.	Exercises – 6 randomised: side-lie hip abd; stand hip abd NWB; stand hip abd hip flex 30^0 NWB; pelvic drop; stand hip abd; stand hip abd with hip flex 30^0. NWB exs had cuff weight 3% body weight on (R) leg. Repetitions – 15 to a metronome (60 bpm) of 1 beat up, 1 beat down and 1 beat rest. 8-10 practice reps 10 mins before testing. Rest - 3 mins between exs.	pelvic drop 57 (32); stand abd with hip flex 30^0 46 (34); stand abd 42 (27); side-lie abd 42 (23); stand abd NWB 33 (23); stand abd with hip F 30^0 NWB 28 (21).
Boren et al. (2011) (Cross-sectional) (Exercise data partially extracted)	26 healthy university and surrounds.	Surface (positioned per standard EMG protocol) on dominant limb.	MVIC 3 trials x 5 secs in side-lie abd. 1 min rest between trials.	Exercises – 22 randomised including: SL squat; clam hip flex.45^0; side-lie abd; lateral step-up; skater squat; pelvic drop; SL bridge stable; forward step-up; SL bridge unstable. Repetitions – 8 to a metronome (60 bpm) of 1 beat up and 1 beat down including 3 practice reps. Rest – 2 mins between exs.	SL squat 82.26; side-lie abd 62.91; lateral step-up 59.87; skater squat 59.84; pelvic drop 58.43; SL bridge stable 54.99; forward step-up 54.62; SL bridge unstable 47.29; clam hip flex. 45^0 47.23.
Boudreau et al. (2009) (Cross-sectional)	44 (22 M) healthy. 23.3 (5.1) years; 174.5 (9.1) cm; 74.6 (16.5) kg	Surface (33% iliac crest to greater trochanter ant to the GMax) bilaterally.	MVIC 3 trials x 3 secs in stand hip abd. 30 sec rest between trials.	Exercises – 3 randomised: SL squat; lunge; step-up and over. Repetitions – 3 trials for each ex. 2 practice trials before. Rest – 30 secs between trials and 2 mins between exs.	DOM: SL squat 30.1 (9.1); lunge 17.7 (8.8); step-up and over 15.2 (6.9). Non-DOM: lunge 19.0 (11.7); step-up and over 16.8 (10.4); SL squat 12.0 (7.5).
Bouillon et al. (2012) (Cross-sectional)	40 (20 M) healthy active university and surrounds. 23.2 (1.9) years (M), 22.4 (1.8) years (F); 1.8 (.09) m (M), 1.6 (.07) m (F); 87.8 (20) kg (M), 42.5 (7) kg (F).	Surface (3cm inf. to iliac crest) on dominant limb.	MVIC 3 trials x 5 sec in side-lie abd., neutral rotation, slight hip ext. 3 secs rest between trials and 5 mins between MVIC and exs.	Exercises - 3 randomised: step down; forward lunge; side lunge. Repetitions – 1 trial of 10 to metronome (80 bpm) with 4 beats per repetition 10 practice reps before. Rest – 30 secs between sets	step down (M & F) 14 (3); side lunge (M) 13 (3), (F) 13 (2); lunge (M & F) 12 (2).

Weight-bearing exercises

Squat exercises

Gluteus medius

Single leg squats were evaluated in 15 studies[48,52,57,64,65,67,68,70,81,83-88] using predominantly single surface electrode measures at middle GMed (Table 5). Moderate activity (39.03 [95% CI 31.21, 48.82] % MVIC) was reported when 13 studies were pooled together (Figure 8). Large variations did however exist between the studies including squat depth, exercise technique and number of repetitions. One study[52] recorded activity in all three GMed segments using surface electrodes and found very high activity in all three segments (90% MVIC anterior, 92% MVIC middle, and 87% MVIC posterior). Another study[62] measured GMed segmental activity for the single leg squat with isometric hip abduction and

Table 2. *Summary of included gluteus medius studies. (continued)*

Cambridge et al. (2012) (Cross-sectional) (Exercise data partially extracted)	9 healthy males university. 22.6 (2.2) years; 181.9 (9.2) cm; 85.8 (15.4) kg.	Surface bilaterally	MVIC 1 trial side-lie abd.	Exercises – 2 randomised: sumo walks with elastic resistance band at 3 different positions for each ex. Repetitions – 3 trials for each ex. Practice reps before.	Sumo walk with feet band ~ 35 (12); sumo walk with ankle band ~ 29 (8); sumo walk with knee band ~ 24 (8.5).
Chan et al. (2017) (Cross-sectional)	20 (10 M) healthy university. 21.10 (1.70) years, 166.75 (7.90) cm; 58.10 (9.20).	Surface (33% iliac crest to greater trochanter)	MVIC side-lie abd, neutral rotation and slight ext.	Exercises – 2 randomised: clam hip flex 45^0; side-lie abd with normal core activation and enhanced core activation. Repetitions – 3 trials to metronome (60 bpm). 3 secs up, 3 secs hold, 3 secs down. Practice reps before. Rest – 3 sec between trials and 1 min between exs.	Enhanced core: side-lie abd 31.38 (12.02); clam hip flex 45^0 18.39 (10.66). Normal core: side-lie abd 28.89 (7.92); clam hip flex 45^0 15.63 (10.53).
Cynn et al. (2006) (Cross-sectional)	18 (9 M) healthy university. 23.5 (3.5) years; 59.3 (5.1) kg; 167.7 (4.3) years.	Surface (33% iliac crest to greater trochanter) on dominant limb.	MVIC 3 trials side-lie abd.	Exercises - 2: side-lie abd; side-lie abd with pressure biofeedback unit. Repetitions – 5 sec hold. Practice reps before.	Side-lie abd 25.03 (10.25); side-lie abd with pressure biofeedback unit 46.06 (21.20).
Distefano et al. (2009) (Cross-sectional) (Exercise data partially extracted)	21 (9 M) healthy recreationally active. 22 (3) years; 171 (11) cm; 70.4 (15.3) kg.	Surface (33% greater trochanter to iliac crest) on dominant limb.	MVIC 3 trials x 5 secs in side-lie 25^0 abd. 1 practice trial before.	Exercises – 9 randomised including clam hip flex 30^0; clam hip flex 60^0; side-lie hip abd; SL squat; forward lunge; sideways lunge; transverse lunge; lateral band walk. Repetitions – 8 to metronome (60 bpm) with 2 beats up and 2 beats down. Practice reps before. Rest – 2 mins between exs. 5 mins between exs and MVIC.	Side-lie hip abd 81 (42); SL squat 64 (24); lateral band walk 61 (34); transverse lunge 48 (21); forward lunge 42 (21); clam hip flex 30^0 40 (38); sideways lunge 39 (19); clam hip flex 60^0 38 (29).
Dwyer et al. (2013) (Cross-sectional) (Exercise data extracted for healthy controls)	17 healthy local controls. 50.8 (1.4) years; 173.1 (2.5) cm; 77.3 (3.8) kg.	Surface (33% iliac crest to greater trochanter) bilaterally.	MVIC 3 trials x 3 secs in stand hip abd on stance leg. Practice trials before. 30 sec rest between trials.	Exercises – 2 randomised: step-up; step-down Repetitions – 3 trials for each limb to a metronome (55bpm) Rest – 30 secs between trials and 2 mins between exs.	DOM step up 29.4 (2.4); non-DOM step up 28.9 (2.5); non-DOM step down 22.1 (4.5); DOM step down 19.9 (1.7).
Dwyer et al. (2010) (Cross-sectional)	42 (21 M) healthy asymptomatic. 23 (5.8) years (F), 23 (4.0) years (M); 167.6 (5.1) cm (F), 181.4 (7.4) cm (M); 63.7 (5.9) kg (F), 85.6 (16.5) kg (M).	Surface[107] bilaterally.	MVIC 3 trials x 3 secs in stand abd. 30 sec rest between trials.	Exercises – 3 randomised: SL squat; lunge; step-up-and-over. Repetitions – 3 trials for each ex. Practice reps before. Rest – 30 secs between trials and 2 mins between exs.	Concentric and eccentric phases DOM; SL squat 31.2 (10.9), 25.3 (11.5) (M), 29.5 (7.5), 26.6 (6.8) (F); step-up-and–over 15.5 (7.9), 14.4 (9.6) (M), 16.5 (5.7), 14.5 (4.6) (F); lunge 11.6 (8.3), 15.5 (9) (M), 11.4 (4.8), 17.8 (8.8) (F). Concentric and eccentric phases non-DOM; SL squat 11.6 (6.1), 10.6 (5.8) (M), 12.5 (9.3), 12.6 (9) (F); lunge 17.2 (7.3), 14.8 (4.7) (M), 24.6 (18.1), 20.8 (15.9) (F); step-up-and-over 14.8 (3.8), 13.3 (4.6) (M), 20.7 (14.6), 18.7 (14.3) (F).
Ekstrom et al. (2007) (Cross-sectional) (Exercise data partially extracted)	30 (19 M) healthy university. 27 (8) years; 176 (8) cm; 74 (11) kg.	Surface (ant-sup. to GMax and inf. to the iliac crest) applied unilaterally.	MVIC 3 trials x 5 secs in side-lie neutral hip rot, slight ext, end AROM abd. 30 sec rest between trials.	Exercises – 8 randomised including: side-lie hip abd; bridge; SL bridge with opposite knee ext; lateral step-up; stand lunge. Repetitions – 3 for trunk stabilisation exercises held for 5 secs; lateral step-up and lunge held 5 secs at max knee. flex; Practice reps before. Rest – 30 secs between trials; 1 min between exs.	SL bridge 47 (24); lateral step-up 43 (18); side-lie abd 39 (17); lunge 29 (12); bridge 28 (17).
Felicio et al. (2011) (Cross-sectional)	15 healthy sedentary females with misalignment of lower limb. 22.26 (2.22) years; 161.7 (7.33) cm; 56.56 (4.68) kg.	Surface[108] bilaterally.	MVIC 3 trials x 6 secs in side-lie 20^0 abd, 10^0 ext.	Exercises – 3 randomised with 25% additional body weight: ball wall squat; ball wall squat with add; ball wall squat with abd. Repetitions – 3 trials for each ex. held for 6 secs. Rest – 2 mins between trials.	DOM: squat with add 59 (22); squat with abd 47 (20); squat 33 (27). Non-DOM: squat with add 59 (27); squat with abd 52 (24); squat 26 (13).
Ganderton et al. (2017) (Cross-sectional) (Exercise data partially extracted)	10 healthy post-menopausal women. 60.2 (2.7) years; 164.7 (4.3) cm; 70.0 (10.2) kg.	Fine-wire into 3 GMed segments (anterior, middle & posterior) via standardised landmarks on dominant leg.	MVICs 3 trials x 5 secs in side-lie hip abd, side lie clam, seated hip ER / IR to determine max for each segment. 3 min rest between trials.	Exercises – 7 exercises randomised including: hip hitch; hip hitch with toe tap; hip hitch with hip swing; isometric hip abduction; dip test; clam hip flex 45^0. Repetitions – 2 sets of 6 reps to metronome 2 secs concentric and 2 secs eccentric for dynamic exs. 3 reps of 15 secs hold for isometric exs. Rest – 1 min between isometric reps and dynamic sets; 2 mins between each ex.	Anterior GMed: hip hitch swing 82.18 (54.71); hip hitch 68.74 (40.98); hip hitch toe tap 75.60 (47.82); dip test 44.75 (29.11); stand isometric hip abd 55.65 (49.65); clam 3.06 (2.81). Middle GMed: dip test 71.06 (64.53); hip hitch swing 66.26 (38.37); hip hitch 65.90 (47.54); hip hitch toe tap 57.91 (43.51);; stand isometric hip abd 29.81 (18.81); clam 13.26 (16.34). Posterior GMed: hip hitch 73.80 (53.89); hip hitch swing 72.15 (43.32); hip hitch toe tap 45.55 (13.10); stand isometric hip abd 40.52 (44.30); dip test 28.35 (14.29); clam 22.79 (17.03).

with isometric hip adduction. They found moderate activity for both exercises for the middle (27-31% MVIC) and posterior (22-33% MVIC) segments but high anterior segmental activity (42% MVIC) for isometric adduction, and low anterior segmental activity (19% MVIC) for isometric abduction.

Single leg wall squats were evaluated in four studies.[63,83,84,88] When pooled together for the middle GMed segment were found to generate moderate activity (32.26 [23.74, 43.84] % MVIC) (Figure 8) (Table 5). Two studies[62,63] recorded segmental GMed activity using surface electrodes but one of the studies[62] had the

Table 2. *Summary of included gluteus medius studies. (continued)*

Harput et al. (2016) (Cross-sectional) (Exercise data partially extracted for healthy controls)	15 (8 M) healthy controls 26.3 (6.6) years; 171.6 (10.8) cm; 75.1 (9.2) kg.	Surface (50% iliac crest to greater trochanter) on dominant leg.	MVIC 3 trials x 5 secs in stand hip abd on stance leg. 1 practice trial before. 30 secs between trials.	Exercises - 3 exercises including step down. Repetitions – 3 reps in 2 directions for SEBT (4 practice reps); 5 for step down to metronome (75bpm) (1 practice rep).	Step down ascending 28.2 (10.4), descending. 27.5 (11.4).
Hatfield et al. (2016) (Cross-sectional)	20 (10 M) healthy university. 26.6 ± 5.1 years; 1.73 ± 0.08 m; 66.1 ± 9.2 kg.	Surface[105] randomly allocated to a side.	MVIC 2 trials x 3 secs in prone hip abd. Practice trials before.	Exercises – 4 randomised: SL squat; step down; half step down; step up. Repetitions – 5 reps to metronome (1Hz) 4 sec count. Practice reps before.	Step down 27.42 (7.37); (2) half step down 21.23 (6.2); SL squat 23.71 (5.98); step up 16.87 (4.34).
Heo et al. (2013) (Exercise data partially extracted)	15 healthy females. 23.53 (3.15) years; 162.06 (4.78) cm; 52.60 (4.84) kg.	Surface for 3 GMed segments: anterior (50% ASIS to greater trochanter); middle (50% iliac crest to greater trochanter); and posterior. (33% posterior ilium to greater trochanter)	MVIC hip abd.	Exercises – 4 including SL wall squat with abd; SL wall squat with add; SL squat with abd; SL squat with add. Repetitions – 3 reps for 5 sec holds for each ex. Rest - 30 secs between reps and 1 min between exs.	Anterior GMed: SL squat with add 42.11 (20.63); SL wall squat with abd 28.72 (14.7); SL squat with abd 19.36 (13.32); SL wall squat with add 15.66 (10.50). Middle GMed: SL wall squat with abd 32.95 (10.86); SL squat with add 31.32 (17.38); SL squat with abd 26.84 (13.20); SL wall squat with add 20.69 (9.56). Posterior GMed: SL wall squat with abd 43.81 (19.42); SL squat with abd 32.99 (10.84); SL wall squat with add 27.97 (19.78); SL squat with add 22.43 (10.10).
Hertel et al. (2005) (Cross-sectional) (Exercise data extracted for no orthotic condition)	30 (15 M) healthy recreationally active equally divided into 3 groups depending on foot-type (pes planus, pes cavus, pes rectus). 21.1 (1.6) years; 170.2 (6.1) cm; 69.1 (13.9) kg.	Surface (50% iliac crest to greater trochanter) on leg contralateral to dominant throwing arm.	MVIC 3 trials in SL stance in a custom-made device. 90 secs rest between trials.	Exercises – 2 randomised: SL squat; lateral step-down. Repetitions – 3 trials for each ex. Metronome (60 bpm) 2 secs down, 2 secs up for lateral step down. Rest – 5 mins between each orthotic condition.	SL squat ~ 77 (5); lateral step down ~ 74 (6).
Ju & Yoo (2017) (Cross-sectional) (Exercise data partially extracted)	15 healthy males. 29.1 (2.9) years; 173.4 (7.1) cm; 71.7 (8.5) kg.	Surface anterior segment (50% ASIS to greater trochanter).	MVIC in side-lie abd.	Exercises – 4 including pelvic drop. Repetitions – 5 secs contraction.	Pelvic drop 25.40.
Ju & Yoo (2016) (Cross-sectional) (Exercise data partially extracted)	15 healthy males. 29.13 (2.85) years, 173.4 (7.08) cm, 71.73 (8.52) kg.	Surface for 3 GMed segments: anterior (50% ASIS to greater trochanter); middle (50% iliac crest to greater trochanter); posterior (33% distance posterior ilium to greater trochanter).	MVIC in side-lie abd, prone hip ER, and prone hip IR to determine max. for each segment. 30 secs rest between trials.	Exercises – 4 including pelvic drop. Repetitions – 3 trials for each ex. 2 secs up, 2 secs down. Rest – 30 secs between trials and 1 min between exs.	Anterior GMed: pelvic drop 25.40 (7.77). Middle GMed: pelvic drop 23.43 (8.65). Posterior GMed: pelvic drop 21.63 (9.06).
Kang et al. (2014)	17 healthy males. 23.06 (1.47) years; 172.88 (5.65) cm; 68.29 (4.69) kg.	Surface[109] on dominant limb.	MVIC 2 trials x 5 secs in side-lie abd. 1 min rest between trials.	Exercises – 2: squat; squat with resisted shoulder flex. Repetitions – 3 trials to metronome (3 secs down and 3 secs up).	Eccentric phase: squat with resisted shoulder flex 12.09 (6.29); squat 8.82 (3.91). Concentric phase: squat with resisted shoulder flex 11.58 (5.96); squat 8.44 (3.59).
Kim et al. (2015) (Cross-sectional) (Exercise data partially extracted)	10 healthy males 31 (4.2) years; 176.8 (8.3) cm; 76.7 (8.1) kg.	Surface (33% iliac crest to greater trochanter) bilaterally.	MVIC 3 trials in side-lie 5^0 abd.	Exercise – 2 including side-lie abd. Repetitions – 3 trials, 5 secs hold. Rest – 30 secs between trials.	Side-lie abd. 24.30 (5.45).
Krause et al. (2018) (Cross-sectional) (Exercise data partially extracted)	30 (15 M) healthy. 23.9 (1.7) years, BMI 24.21 (2.88).	Surface (33% iliac crest to greater trochanter) on dominant limb.	MVIC 1 trial x 5 secs in side-lie abd 5^0. 1 submaximal practice trial before.	Exercise – 2 including lunge. Repetitions – 3 to a metronome, 3 secs down, 1-2 secs hold, 3 secs up. Practice trials before.	Lunge 15.3 (11.4)
Krause et al. (2009) (Cross-sectional) (Exercise data partially extracted)	20 (6 M) healthy recreationally active. 23.6 (1.7) years (F), 26.3 (2.5) years (M); 169.3 (9.5) cm (F), 172.2 (12.9) cm (M); 65 (9.2) kg (F), 85 (10.1) kg (M).	Surface (50% greater trochanter to iliac crest) on dominant limb.	MVIC 3 trials in side-lie abd 30^0, slight hip ext. Adequate rest between trials.	Exercises – 5 randomised including SL squat; SL squat on Airex cushion. Repetitions – 3 trials for each ex. Stance exs held for 10 secs and squats for 3 reps. Practice reps before. Rest – adequate rest between each set of exs.	SL squat on Airex 58.5 (35.32); SL squat 47.79 (22.61).
Lee et al. (2013) (Cross-sectional)	20 healthy with normal ITB length and BMI < 25. 22.3 (1.9) years, 168.7 (7.2) cm; 65.5 (12.4) kg.	Surface (33% iliac crest to greater trochanter) on dominant limb.	MVIC 2 trials x 5 secs in side-lie abd 50% AROM, slight ext and ER. 30 secs rest between trials.	Exercises – 3 randomised: side-lie abd.; side-lie abd. + IR; side-lie abd + ER. Repetitions – 3 trials x 5 sec hold. Rest – 3 mins between exs.	Side-lie abd. + IR 45.3 (20.5); side-lie abd + ER 35.3 (12.5); side-lie abd 34.2 (11.8).

single leg wall squat performed using either isometric hip abduction or isometric hip adduction. Low to moderate activity (13-29% MVIC) was reported in the anterior segment and moderate to high activity (28-44% MVIC) in the posterior segment (Figures 5 and 6).

Squats with or without medial or lateral resistance, or wall support were evaluated in six studies[54,57,61,78,89,90] using single surface electrodes placed on middle GMed (Table 5). When pooled together, squats generated low activity levels (17.64 [10.70, 29.09] % MVIC) and squats with resisted abduction moderate activity levels (35.38 [16.38, 76.40]% MVIC) for the middle GMed segment (Figure 8).

Gluteus minimus

Moderate (25% MVIC anterior) to high (46% MVIC posterior) activity was generated for both segments of GMin during the single leg squat in one study[47] (Figures 3 and 4) (Table 6).

Table 2. *Summary of included gluteus medius studies. (continued)*

Lee et al. (2014) (Cross-sectional)	19 (8 M) healthy with weak GMed and BMI < 25. 21 (1.73) years; 166 (.07) cm; 59.79 (9.61) kg.	Surface (33% iliac crest to greater trochanter) on dominant limb.	MVIC 2 trials x 5 secs in side-lie abd 50% AROM, slight ext and ER. 3 mins rest between trials.	Exercises – 3 randomised: side-lie abd; side-lie abd + IR; side-lie abd + ER. Repetitions – 3 trials x 5 sec hold. Rest – 3 mins between exs.	Side-lie abd + IR ~ 61.34 (4); side-lie abd + ER ~ 48.96 (7); side-lie abd ~ 45.22 (6).
Lehecka et al. (2017) (Cross-sectional)	28 (12 M) healthy. 23.43 (2.28) years; 1.73 (0.11) m; 72.57 (13.93) kg.	Surface (inf. to lat. aspect of iliac crest on a line to greater trochanter) on dominant limb.	MVIC 3 trials x 7 secs in side-lie abd end range, slight ext. 30 secs rest between trials.	Exercises – 5 randomised: SL bridge with knee flex 90^0; SL bridge with knee flex. 135^0; SL bridge with knee flex 90^0 opposite leg bent; SL bridge with knee flex 90^0 ankle DF, opposite leg bent; SL bridge with knee flex 135^0 ankle DF, opposite leg bent. Repetitions – 8 to metronome (60 bpm) for each including 2 practice reps before.	SL bridge with knee flex 90^0 57.81 (20.72); SL bridge knee flex 135^0 57.23 (27.82); SL bridge knee flex 90^0, opposite leg bent 55.05 (20.71); SL bridge knee flex 90^0 ankle DF, opposite leg bent 54.27 (20.01); SL bridge knee flex 135^0 ankle DF, opposite leg bent 41.63 (18.19).
Lin et al. (2016) (Cross-sectional) (Exercise data partially extracted)	12 (6 M) healthy. 26.1 (4.7) years; 168.8 (2.7) cm; 63.6 (9.6) kg.	Surface (33% greater trochanter to iliac crest) on dominant limb.	MVIC 2 trials x 5 secs in side-lie hip abd. 30 secs rest between trials.	Exercises – 3: clam hip flex 60^0; SL squat; lunge. Repetitions – 5 for each ex. to a metronome (1 rep per 2 secs).	Clam 19.1 (8.8); SL squat 18.4 (7.9); lunge 8.2 (3.8).
Lubahn et al. (2011) (Cross-sectional)	18 healthy females; 22.3 (2.3) years; 166.82 (9.2) cm; 61.1 (7.1) kg.	Surface[107] on dominant limb.	MVIC 3 trials x 5 secs in side-lie abd. with neutral hip.	Exercises – 4 randomised: squat; squat with lateral resistance band; step-up; SL squat. Repetitions – 5 for each ex. to a metronome (40 bpm) with 1 beat for start of rep. then beat 2 at midpoint then beat 3 for end of rep. Several practice reps before. Rest - 10-15 secs between reps. 45-60 secs rest between each ex.	SL squat 65.6 (23.8); step-up 48.2 (20.4); squat with lateral resistance band 23.7 (16.3); squat 20.8 (14.7).
MacAskill et al. (2014) (Cross-sectional) (Exercise data partially extracted)	34 (14 M) healthy. 21.2 (1.8) years (M), 21.7 (1.6) years (F); 177.8 (15.3) cm (M), 163.2 (6.7) cm (F); 77.1 (8.9) kg (M), 58.1 (6.2) kg (F).	Surface (2-3 cm distal to midpoint iliac crest) on dominant limb.	MVIC 3 trials x 5 secs in side-lie abd 50% AROM. 1 sec rest between trials.	Exercises – 4 randomised including forward step-up; lateral step-up; 10 RM side-lie abd with cuff weight. Repetitions – 3 trials of 5 reps, 2 secs for each rep Rest – 3 mins between sets	10 RM side-lie abd ~ 100 (23); lateral step-up ~ 63 (21); forward step-up ~ 62 (19).
Mauntel et al. (2013) (Cross-sectional)	40 (20 M) healthy active divided equally into 2 groups – control and medial knee displacement (MKD). 20.2 (1.5) years, 20.2 (1.8) years (MKD); 173.1 (10.1) cm, 173.8 (8.8) cm (MKD); 71 (14.6) kg, 71.8 (14.7) kg (MKD).	Surface on dominant limb.	MVIC 3 trials x 5 secs in side-lie abd. 1 min rest between trials.	Exercise – 1: SL squat Repetitions – 5 trials to a metronome (60 bpm). 2 beats down, 2 beats up. Rest – 1 min between trials.	Control group: SL squat 37.1 (17.3). MKD group: SL squat 32.9 (17.2).
McBeth et al. (2012) (Cross-sectional)	20 (9 M) healthy community runners (> 40 km / week). 25.45 ± 5.8 years (M), 26.1 ± 5.2 years (F); 1.75 ± 0.08 m (M), 1.68 ± 0.03 m (F); 69.3 ± 7.1 kg (M), 61.3 ± 6.6 kg (F).	Surface (33% iliac crest to greater trochanter) on dominant limb.	MVIC 3 trials x 5 secs in side-lie abd 35^0, slight ext. and ER. 10 sec rest between trials.	Exercises – 3: side-lie abd; side-lie abd + ER; clam hip flex 45^0. All performed with 5% body weight cuff weight. Repetitions – 7 set to a metronome (60 bpm) of 1 beat up, 1 beat down, and 4 beat rest. 4 practice sets of 5 reps before. Rest - 1 min between exs. 2 mins between MVIC testing and exs.	side lie abd 79.1 (29.9); side-lie abd + ER 53.03 (28.4); clam hip flex 45^0 32.6 (16.9).
Monteiro et al. (2017) (Cross-sectional)	17 (6 M) healthy sedentary, BMI (19-25 kg/m^2). 25.6 (1.4) years; 168.29 (8.64) cm; 70 (9.98) kg.	Surface (50% iliac crest to greater trochanter) on dominant limb.	MVIC 3 trials x 3 secs in side-lie abd 30^0. 1 min rest between trials.	Exercises – 3 randomised: pelvic drop; pelvic drop + hip IR; pelvic drop + hip ER. Repetitions – 2 trials of 4 to metronome (60 bpm). 60 practice reps for each ex before.	pelvic drop + IR 42.43 (15.45); pelvic drop 42.11 (18.39); pelvic drop + ER 32.77 (14.01).
Morimoto et al. (2018) (Cross-sectional) (Exercise data partially extracted)	11 healthy. 22 (2) years; 174 (7.5) cm; 71,7 (13.5) kg.	Surface on dominant limb.	MVIC in side-lie abd.	Exercises – 7 including side-lie abd; side-lie abd + hip ER; side-lie abd + hip IR.	Side-lie abd + ER 40.5 (16.9); side-lie abd 38 (14.2); side-lie abd + IR 36.3 (16.7).
Noh et al. (2012) (Cross-sectional)	15 (10 M) healthy. 25.07 (3.59) years; 172.07 (5.03) cm; 65.93 (6.31) kg.	Surface (33% iliac crest to greater trochanter) on dominant limb.	MVIC 2 trials x 5 secs in side-lie abd.	Exercises – 3 randomised: lateral step up; lateral step up + hip IR; lateral step up + hip ER. Repetitions – 3 trials for 2 secs up to a metronome. Rest – 1 min between trials and 5 mins between exs.	lateral step-up + IR 41.27 (13.16); lateral step-up 38.81 (13.01); lateral step-up + ER 30.17 (9.81).
Oliver et al. (2010) (Cross-sectional) (Exercise data partially extracted)	30 healthy active college students. 23.4 (1.4) years; 171.3 (10.3) cm; 73.3 (16.2) kg.	Surface[110] bilaterally.	MVIC 2 trials x 5 secs in side-lie abd.	Exercises – 4 randomised including bridge and SL bridge. Repetitions – 3 for each ex. Held for 10 secs. Practice reps before.	(L) side: (R) SL bridge ~ 35 (17); bridge ~ 17 (11); (L) SL bridge ~ 10 (13). (R) side: (L) SL bridge ~ 33 (16); bridge ~ 17 (9); (R) SL bridge ~ 14 (14).

Step exercises

Gluteus medius

Step exercises were evaluated in 21 studies[5,48,49,51-53,57,64,65,68,71,77,78,83-85,88,91-94] for predominantly single electrode surface measures of middle GMed (Table 5). For studies that could be pooled together, high mean activity levels (44.98 (95% CI (34.54, 58.58))% MVIC) were generated for the lateral step-up and moderate mean activity levels (35.23 (24.52, 50.60)% MVIC) were elicited for the forward step-up (Figure 9). Adding resistance to a side-step exercise also generated high mean activity levels (40.04

Table 2. *Summary of included gluteus medius studies. (continued)*

Oliver & Stone (2016) (Cross-sectional) (Exercise data partially extracted)	28 healthy active college students. 22 (2) years; 168 (8) cm; 66 (10) kg.	Surface[107] on dominant limb.	MVIC 3 trials x 5 secs in side-lie abd.	Exercises – 2 including SL step down.	SL step down 187 (80).
O'Sullivan et al. (2013) (Cross-sectional) (Exercise data partially extracted for control group)	12 healthy active women. 21 (1) years; 164.6 (7.9) cm; 62.6 (9.9) kg.	Surface for 3 GMed segments: anterior (50% ASIS to greater trochanter); middle (50% greater trochanter to iliac crest); posterior (33% posterior ilium to greater trochanter) on dominant limb.	MVIC 3 trials x 5 secs in side-lie abd including 2 practice trials. 30 sec rest between trials	Exercises – 4 non-randomised including pelvic drop; step up and over; SL squat. Repetitions – 3 for each ex. Step up and over held for 5 secs. Pelvic drop and SL squat 2 secs down, 2 secs up to a metronome (60 bpm). 3 practice trials before. Rest – 30 secs between trials and 2 min rest between exs.	Anterior GMed: SL squat 89.6 (24.6); step up and over 88.4 (19.6); pelvic drop 79.9 (24.8). Middle GMed: SL squat 91.7 (36.9); pelvic drop 87.6 (32.6); step up and over 85.4 (29.6). Posterior GMed: pelvic drop 87.9 (23.9); SL squat 86.7 (16); step up and over 81.2 (28.8).
O'Sullivan et al. (2010) (Cross-sectional) (Exercise data partially extracted)	15 (7 M) healthy university. 22 (4) years; 170 (12) cm; 68 (12) kg.	Surface for 3 GMed segments: anterior (50% ASIS to greater trochanter); middle (50% greater trochanter to iliac crest); posterior (33% posterior ilium to greater trochanter) on (R) limb.	MVIC 3 trials x 5 secs in stand hip 30^0 abd, neutral flex / ext / ER / IR; prone hip ER; and prone hip IR to determine max for each segment. 30 sec rest between trials.	Exercises – 3 randomized including SL wall squat; pelvic drop. Repetitions – 3 for each ex. with wall squat held for 5 secs. Pelvic drop 2 secs down and 2 secs up. 3 practice reps for each ex. before. Rest – 30 secs between reps and 1 min between exs.	Anterior GMed: pelvic drop 21.12 (6.80); SL wall squat 13.30 (7.50). Middle GMed: pelvic drop 28.45 (8.49); SL wall squat 24.60 (8.89). Posterior GMed: pelvic drop 38.17 (16.76); SL wall squat 34.82 (19.86).
Petrofsky et al. (2005) (Cross-sectional) (Exercise data partially extracted)	6 (4 M) healthy. 25.3 (1.5) years; 169.9 (6.7) cm; 69.8 (9.6) kg.	Surface (over muscle belly and 2 cm distal) on (R) limb.	MVIC 3 trials x 3 secs in side-lie hip abd 1 min rest between trials.	Exercises – 6 including 45^0 squat; 90^0 squat.	90^0 squat 28.4 (6.7); 45^0 squat 22.1 (9.3).
Philippon et al. (2011) (Cross-sectional) (Exercise data partially extracted)	10 (5 M) healthy. 28.7 (2.0) years; 1.72 (0.04) m; 67 (4.3) kg	Fine-wire (2.5 cm distal to midpoint of iliac crest under US guidance).	MVIC 3 trials x 3 secs in stand hip abd, slight hip ER. 3-5 sec rest between trials.	Exercises – 13 randomised including bridge; clam hip – knee flex 45^0; clam hip neutral, knee flex 90^0; side-lie abd with hip IR; side-lie abd with hip ER; side-lie abd with hip ext; SL bridge. Repetitions – 2 trials of 5 for each ex. to a metronome.	Concentric phase: SL bridge 35.1 (33.8); side-lie abd. + IR 33.3 (27.2); side-lie abd + ext 31.4 (22.5); side-lie abd + ER 23.3 (17.7); clam flex 45^0 16.7 (13.6); bridge 10.8 (8.9).
Selkowitz et al. (2013) (Cross-sectional) (Exercise data partially extracted)	20 (10 M) healthy university. 27.9 (6.2) years.	Fine-wire (2.5 cm distal to midpoint of iliac crest) on dominant limb.	MVIC 1 trial X 5 secs in side-lie abd 30^0, neutral flex.	Exercises – 11 randomised including side-lie abd; bridge; elastic resistance clam hip flex 45^0; hip hike; lunge; elastic resistance side-step; squat; step up; SL bridge. Repetitions – 5 for each ex to a metronome (40bpm). Side-step 3 trials x 2 strides in each direction to metronome (80 bpm). Rest – 2 mins between exs.	Side-lie abd 43.5 (14.7); hip hike 37.7 (15.1); SL bridge 30.9 (20.7); side-step 30.2 (15.7); step-up 29.5 (14.9); clam flex 45^0 26.7 (18); lunge 19.3 (12.9); bridge 15 (10.5); squat 9.7 (7.3).
Sidorkewicz et al. (2014) (Cross-sectional)	13 healthy males. 24.8 (4.2) years; 179.7 (5.4) cm; 75.9 (9.8) kg.	Surface[105] on (R) limb.	MVIC 3 trials in side-lie abd. 2 mins rest between trials.	Exercises – 6 randomised: side lie abd; side lie abd + hip IR; side lie abd + hip ER; clam hip flex 30^0; clam hip flex 45^0; clam hip flex 60^0. Repetitions – 3 trials for each ex. Practice reps before.	side lie abd + IR 48.67 (20.21); side lie abd 36.70 (14.55); side lie abd + ER 36.50 (16.46); clam hip flex 60^0 36.49 (33.06); clam hip flex 45^0 35.55 (34.25); clam hip flex 30^0 26.80 (24.08).
Sinsurin et al. (2015) (Cross-sectional) (Exercise data partially extracted)	9 healthy sedentary males. (18-25 years); BMI (18.5-23 kg/m^2); dominant (R) limb.	Surface (50% iliac crest to greater trochanter) bilaterally.	MVIC 3 trials x 3 secs in side-lie abd, neutral hip. 3 submaximal practice trials before. 90 secs rest between trials.	Exercises – 7 randomised including (L) stance, (R) hip abd Repetitions – 3 trials Rest – 30 secs between trials. 2 mins between exs.	(L) stance limb: hip abd 43.71 (15.05); (R) swing limb: hip abd 63.59 (41.16);
Souza & Powers (2009) (Cross-sectional) Exercise data partially extracted for controls)	20 healthy females. 26 (5) years; 1.7 (0.6) m; 62.9 (6.6) kg.	Surface (2.5cm inferior to iliac crest) on 13 matched (R) and 7 matched (L) limbs.	MVIC 1 trial x 5 secs in side-lie abd 20^0, 5^0 ext.	Exercise – 3 including step down Repetitions – 3 trials, 2 secs down, 2 secs up to a metronome.	Step down ~ 17 (5).
Webster & Gribble (2012) (Cross-sectional) (Exercise data partially extracted for controls)	9 healthy active controls. 22.9 (4.6) years; 164.5 (6.5) cm; 65.4 (10) kg.	Surface (2.5 cm below iliac crest) on matched assigned limb.	MVIC 3 trials x 10 secs in side-lie abd. 1 min rest between trials. 2 mins rest before exs.	Exercises – 2 randomised: rotational lunge; SL squat with rotational reach. Repetitions – 10 to metronome (72 bpm) – 2 beats out, 2 beats back. Rest – 2 mins between exs.	rotational lunge ~ 68 (32); rotational squat ~ 66 (55).
Willcox & Burden (2013) (Cross-sectional)	17 (10 M) healthy active. 25 (5) years (M), 23 (4) years (F); 182 (8) cm (M), 165 (4) cm (F); 77 (13) kg (M), 60 (11) kg (F).	Surface (33% greater trochanter to iliac crest) on dominant limb.	MVIC 5 secs in side-lie abd.	Exercises – 6 randomised: clam hip flex 0^0; clam hip flex 30^0; clam hip flex 60^0. Exs were then repeated with pelvis reclined 35^0. Repetitions – 10 for each ex. holding for 6 secs. Rest – 3 mins between exs.	Pelvis neutral: clam hip flex 60^0 ~ 22.5 (4.5); clam hip flex 30^0 ~ 21 (5); clam hip flex 0^0 ~ 17 (4). Pelvis reclined: clam hip flex 60^0 ~ 17.5 (4.5); clam hip flex 30^0 ~ 13 (3.5); clam hip flex 0^0 ~ 12.5 (3).
Youdas et al. (2012) (Cross-sectional)	21 (10 M) healthy active university. 25 (3.1) years (M), 24.5 (1.4) years (F); 1.8 (0.1) m (M), 1.7 (0.1) m (F); 82.2 (7.9) kg (M), 69.1 (4.9) kg (F).	Surface[109] bilaterally.	MVIC 1 trial x 5 secs in side-lie abd 30^0.	Exercises – 3 randomised: lateral step against elastic resist, hips neutral; lateral step against elastic resist, hips ER; lateral step against elastic resist, hips IR. Repetitions- 3 for each ex. to metronome (40bpm). Several practice trials before. Rest – 30 – 45 secs between exs.	Stance limb: lateral step hips IR 57.8 (24.3); lateral step hips neutral 49.9 (21.9); lateral step hips ER 47.6 (21.5). Moving limb: lateral step hips IR 43.8 (27); lateral step hips neutral 32.8 (21.9); lateral step hips ER 27.3 (18.1).

[26.53.29, 60.43] % MVIC) for middle GMed (Figure 9). There were wide methodological variations across the studies including exercise technique; step height; step distance; concentric and eccentric phase measures; stepping or supporting leg measures; and addition of external resistance. One study[52] measured segmental surface GMed activity and found very high activity (88% MVIC anterior, 85% MVIC middle, and 81% MVIC posterior) for all three segments for the forward step up and over exercise.

Table 2. *Summary of included gluteus medius studies. (continued)*

Youdas et al. (2014) (Cross-sectional) (Exercise data partially extracted)	26 (13 M) healthy active. 25.3 (3.1) years (M), 23.7 (1.3) years (F).	Surface[109] bilaterally.	MVIC 1 trial x 2-3 secs in side-lie abd 30°. Practice reps before.	Exercises – 4 randomised including reverse cross over pull against elastic resist. Repetitions – 3 reps to metronome (40 bpm). Practice reps before. Rest – 2-3 mins between exs.	Stance limb: reverse cross over pull 50.0 (25.1). Moving limb: reverse cross over pull 52.9 (17.6).
Youdas et al. (2015) (Cross-sectional) (Exercise data partially extracted)	26 (13 M) healthy active. 23.4 (1.3) years (M), 23.5 (1.2) years (F); 1.8 (0.1) m (M), 1.7 (0.1) m (F); 79.7 (10.6) kg (M), 63.7 (7.4) kg (F).	Surface[109] on (R) limb.	MVIC 5 sec in side-lie abd 20°.	Exercises – 6 randomised including DL bridge; DL bridge unstable; SL bridge; SL bridge unstable. Repetitions – 3 reps to metronome (40 bpm). Rest – 1 min between exs.	SL bridge unstable 42 (10.2); SL bridge 40 (11.6); DL bridge 21.4 (7.4); DL bridge unstable 19.9 (10)
Zeller et al. (2003) (Cross-sectional)	18 (9 M) healthy college athletes. 20.33 (1) years (M), 20 (1.5) years (F); 72.44 (2.01) in (M), 67.44 (2.4) in (F); 173.89 (8.94) lbs (M), 141.89 (12.33) lbs (F).	Surface[107] on dominant limb.	MVIC 2 trials x 3 secs in side-lie abd.	Exercises – 1: SL squat Repetitions – 5 with 5 sec duration. Practice reps before.	SL squat 77.3 (64.3) (M), 41 (29.5) (F).

Key: abd – abduction; add – adduction; ant – anterior; ASIS – anterior superior iliac spine; BMI – body mass index; bpm – beats per minute; cm – centimeters; DL – double leg; DOM – dominant limb; ER – external rotation; exs – exercises; ext – extension; F – females; flex – flexion; GMed – gluteus medius; in – inches; inf – inferior; IR – internal rotation; kg – kilograms; kg/m2 – kilograms per metres squared; lat – lateral; lbs – pounds; M – males; max – maximum; m – metres; mins – minutes; MVIC – maximum voluntary isometric contraction; non-DOM – non dominant limb; NWB – nonweight-bearing; PBU – pressure biofeedback unit; post – posterior; reps – repetitions; resist – resistance; secs – seconds; SL – single leg; sup – superior; WB – weight-bearing

Table 3. *Summary of included gluteus minimus studies.*

Study and type	Participant characteristics	EMG electrode type and placement	Normalisation method	Exercise characteristics	Results (% MVIC (SD))
Ganderton et al. (2017) (Cross-sectional)	10 healthy post-menopausal women. 60.2 (2.7) years; 164.7 (4.3) cm; 70.0 (10.2) kg	Fine-wire into 2 segments (anterior & posterior) of GMin via standardised landmarks on dominant limb.	MVICs 3 trials x 5 secs in side-lie abd, side-lie clam, seated hip ER, seated hip IR to find max for each segment. 3 min rest between trials.	Exercises – 7 randomised including hip hitch; hip hitch with toe tap; hip hitch with hip swing; isometric hip abduction; dip test; clam hip flex 45°. Repetitions – 2 sets of 6 reps to metronome 2 secs concentric and 2 secs eccentric for dynamic exs. 3 reps of 15 secs hold for isometric exs. Rest – 1 min between isometric reps and dynamic sets; 2 mins between each ex.	Anterior GMin: hip hitch 68.77 (21.74); hip hitch swing 59.70 (17.26); isometric stand hip abd 54.79 (33.49); hip hitch toe tap 48.30 (16.07); dip test 21.33 (12.30); clam 7.31 (8.94). Posterior GMin: hip hitch swing 78.64 (20.93); hip hitch 83.71 (40.17); hip hitch toe tap 66.73 (25.99); dip test 64.41 (35.54); isometric hip abd 48.62 (30.58); clam 19.59 (20.38).
Moore et al. (2018) (Cross-sectional)	10 (6 M) healthy active university. 23.8 (1.6) years; 177.5 (10) cm; 79.9 (18.5) kg.	Fine-wire into 2 segments (anterior & posterior) of GMin via standardised landmarks on dominant limb.	MVICs 3 trials x 5 secs in side-lie abd, side-lie abd + IR, side-lie clam, side-lie hip flex, side-lie hip IR, prone hip ext to find max for each segment. 3 mins rest between trials.	Exercises – 6 randomised including SL squat; SL bridge; side lie hip abd; clam hip flex 45°. Repetitions – 3 trials of 6 for each ex to a metronome (ranging from 40 – 90 bpm depending on ex). Practice reps before. Rest- 1 – 2 mins between exs and trials. 3 mins between exs and MVIC.	Anterior GMin: side-lie abd 37.62 (14.07); SL squat 25.42 (9.49); SL bridge 13.62 (11.36); clam 2.98 (2.91). Posterior GMin: SL bridge 46.04 (27.83); side-lie abd 43.49 (15.96); SL squat 45.76 (29.99); clam 8.00 (6.44).

Key: abd – abduction; add – adduction; ant – anterior; bpm – beats per minute; cm – centimeters; DL – double leg; DOM – dominant limb; ER – external rotation; ext – extension; flex – flexion; GMed – gluteus medius; GMin - gluteus minimus; inf – inferior; IR – internal rotation; kg – kilograms; lat – lateral; MVIC – maximum voluntary isometric contraction; mins – minutes; non-DOM – non dominant limb; NWB – non-weight-bearing; post – posterior; reps – repetitions; secs – seconds; SL – single leg; sup – superior; WB – weight-bearing.

Lunge exercises

Gluteus medius

The lunge was evaluated in GMed across 10 studies[46,50,64,65,70,71,78,81,92,95] (Table 5). For middle GMed, pooled results suggest moderate activity is recorded during the forward (21.43 [95% CI 14.83, 30.97] % MVIC) and side lunge (22.41 [7.64, 65.78] % MVIC) (Figure 10). One study[46] measured segmental GMed activity with a rear-foot elevated lunge (dip test) and found high anterior (45% MVIC), very high middle (71% MVIC) and moderate posterior (28% MVIC) GMed segmental activity. There was some variation between the studies on lunge technique, active range of movement and movement plane.

Gluteus minimus

One study[46] found the dip test generated moderate activity (21% MVIC) for the anterior GMin segment and very high activity (66% MVIC) for the posterior GMin segment (Figures 3 and 4) (Table 6).

Hip hitch/pelvic drop

Gluteus medius

The hip hitch/pelvic drop exercise were evaluated in eight studies[46,52,55,63,67,68,70,72,78,89,96] (Table 5). For studies that could be pooled together, the hip hitch/pelvic drop generated high GMed anterior activity (40.93 [95% CI 20.61, 81.28] % MVIC), GMed middle (42.64 [30.17, 60.00] % MVIC) and GMed posterior (43.37 [21.33, 88.16] % MVIC) activity (Figures 5, 6 and 11). Three different variations of the hip hitch/pelvic drop exercise were evaluated in one study[46] and found very high activity (68-74% MVIC) for the anterior GMed, and high to very high activity for the middle (41-65% MVIC) and posterior (45-60% MVIC) GMed segments.

Table 4. *Electromyographic technical aspects of included studies.*

Study	EMG unit type	Electrode size and skin preparation	Inter-electrode distance (mm)	Input impedance (Ω)	Common mode rejection ratio (dB)	Amplifier gain	Data filtering (Hz)	Sampling frequency (Hz)	Rectification (full or half wave)	Data processing (ms)
Ayotte et al. (2007)	Nicolet Viking IV	NS; skin debrided and cleansed	30	NS	>110 @ 50-60 Hz	NS	Band pass 30 – 10000	20000	Full	Integrated over 1.5sec
Barton et al. (2013)	Noraxon Telomyo 2400 G2	SENIAM, 2011	20	NS	NS	NS	Band pass 10 – 500 RMS smoothing 100 epoch	1500	Full	Mean amplitude
Berry et al. (2015)	Bagnoli Delsys	10x1mm; skin scrubbed	10	10^{15}	100	NS	Band pass 20 - 390 4th order Butterworth RMS smoothing 100ms	1000	Full	Average RMS
Bolgla et al. (2016)	8 channel Run Technologies	5 mm diameter; skin shaved and cleaned	20	1M	90	2000	Band pass 20 - 500	2000	Full	Average RMS for each repetition
Bolgla et al. (2014)	8 channel Run Technologies	5 mm diameter; skin shaved and cleaned	20	1M	90	2000	Band pass 20 - 500	2000	Full	Average RMS for each repetition
Bolgla and Uhl (2005)	16 channel Run Technologies	5 mm diameter; skin prepared in standard manner	20	NS	90	2000	Band pass 20-500 RMS smoothing 15ms	1000	Full	Average RMS for each repetition
Boren et al. (2011)	Schiller America	NS; skin cleansed	NS	NS	NS	NS	RMS smoothing 50ms	NS	Full	Average amplitude: surround peak activity (100 ms of time)
Boudreau et al (2009)	16 channel Run Technologies	5 mm diameter; skin debrided and cleansed	20	NS	90	2000	Band pass 20-500 RMS smoothing 20ms	1339	Full	Average amplitude
Bouillon et al (2012)	8 channel Noraxon myosystem 900 12 bit A-D converter	NS; skin shaved, abraded and cleaned	20	10M	115	1000	Band pass 10-500 RMS 300	1000	Full	Average activity per repetition
Cambridge et al. (2012)	16 channel AMT 8 Bortec A-D converter	NS	NS	1M	115 @ 60 Hz	NS	Band pass 30-500 Low-pass smoothing: Butterworth 2.5Hz Sampled at 60Hz (synchronisation with kinematic data)	2160	Full	Peak amplitude
Chan et al. (2017)	Myomuscle Noraxon	Skin shaved, abraded and cleaned	10	NS	80	NS	Band pass 10-500 Butterworth 4th order RMS smoothing 500ms	1024	Full	Average amplitude for each repetition
Cynn et al. (2006)	Bagnoli	Skin cleansed	20	NS	NS	NS	Band pass 20-450 Backstop filter (60Hz)	NS	Full	Average amplitude (RMS)
Distefano et al. (2009)	Bagnoli 8 Delsys	NS; skin cleansed	10	NS	>80 @ 60 Hz	10000	Band pass 20-350 RMS smoothing (20ms)	1000	Full	Average amplitude of each repetition
Dwyer et al. (2013)	16 channel Run Technologies	5 mm diameter; skin prepared	20	1M	90	2000	Band pass 20-500 RMS smoothing (30ms)	1000	Full	Average amplitude
Dwyer et al. (2010)	16 channel Run Technologies	5 mm diameter; skin debrided and cleansed	20	1M	90	2000	Band pass 20-500 RMS smoothing (20ms)	1339	Full	Average amplitude for each phase (concentric and eccentric)
Ekstrom et al. (2007)	8 channel Noraxon myosystem 1200	NS; skin debrided and cleansed	20	10M	>100 @ 60 Hz	1000	Band pass 10-500 Butterworth (1st order high-pass, 4th order low-pass) RMS smoothed (20ms)	1000	Full	Average activity of 1 secs surrounding peak amplitude
Felicio et al. (2011)	Myosystem BR 1P84	23x21x5 mm; skin prepared	10	10G	130	20	Band pass 20-500	2000	Full	Average activity (RMS) across the whole repetition
Ganderton et al. (2017)	Delsys Trigno EMG	Stainless steel,teflon-coated 20 cm and 25 cm lengths		NS	>80 @ 60 Hz	1000	Band pass 20-900 Butterworth high-pass, 4th order, 50Hz	2000	Full	Average activity for each repetition

Table 4. *Electromyographic technical aspects of included studies. (continued)*

							Butterworth low-pass smoothed, 4^{th} order, 6Hz			
Harput et al. (2016)	Telemyo DTS Noraxon	10 mm width; skin shaved, abraded and cleaned	20	10m	80	NS	Band pass 10-500 RMS smoothed (25ms)	1000	Full	Average activity in each phase (concentric, eccentric)
Hatfield et al. (2016)	Delsys Trigno	NS	NS	NS	80	NS	Band pass 20-450 Low pass filtered, Butterworth, 4^{th} order, 25 Hz	2000	Full	Integrated activity over entire task
Heo et al. (2013)	Biopac MP150WSW	3 mm diameter; skin shaved and cleaned	NS	NS	NS	NS	Band pass 20 – 500	1000	Full	Average activity (RMS)
Hertel et al. (2005)	Biopac MP 100	10 mm contact area; skin debrided and cleansed	20	2M	11	1000	10-500 RMS smoothing (500ms moving window)	1000	Full	Peak RMS activity within trials
Ju & Yoo (2017)	Biopac MP 150	NS	NS	NS	NS	NS	NS	NS	NS	NS
Ju & Yoo (2016)	EL503 Biopac	3mm diameter	NS	NS	NS	NS	Band pass 20 - 500 RMS of 250 samples	1000	Full	Average (RMS) of the middle 3 seconds of a 5 secs trial
Kang et al. (2014)	Delsys surface EMG	NS	NS	NS	NS	NS	Band pass 20-450	2000	NS	Average activity of each phase (descend and ascend components)
Kim et al. (2015)	Telemyo 2400 T2	NS; skin shaved and scrubbed	20	NS	NS	500	Band pass 30 – 500 RMS smoothed (100ms window)	1500	Full	Average (RMS) for each trial
Krause et al. (2018)	16 bit NI-DAQ PCI-6 220 A-D card Bagnoli 16 amplifier	10 mm; skin scrubbed	10	>1015 @ 100 Hz	92 @ 60 Hz	100 - 10000	Band pass 20 – 450 (Butterworth, 4^{th} order) RMS smoothing (200ms)	1000	Full	Average activity of 1 secs surrounding peak activity of the ascending phase
Krause et al. (2008)	GCS67 Therapeutics unlimited	NS; skin cleansed	22	>15M @ 100 Hz	87 @ 60 Hz	35	RMS smoothed (55ms)	1000	Full	Peak activity over three squats
Lee et al. (2013)	Telemyo DTS	NS; skin shaved and cleansed	NS	NS	NS	NS	Band pass 20 - 450 RMS smoothed (50ms)	1000	Full	Average activity of middle 3 secs of the isometric phase
Lee et al. (2014)	Telemyo DTS	NS; skin shaved and cleaned	20	NS	92 @ 60 Hz		Band pass 20 – 450 RMS smoothed (50ms)	1000	Full	Average activity of middle 3 secs of the isometric phase
Lehecka et al. (2017)	Noraxon telemyo 2400T GT	NS; skin shaved, abraded	NS	NS	NS	NS	Band pass 15 - 500 High-pass filtered (Butterworth, 4^{th} order, 15Hz) Low-pass filtered (Butterworth, 4^{th} order, 500Hz) Moving average smoothed (50ms)	3000	Full	NS
Lin et al. (2016)	Bagnoli Delsys	10x1 mm; skin shaved and cleaned	10	NS	NS	NS	Band pass 20 – 450 Low-pass filtered (12Hz)	1000	Full	Average activity from 5 repetitions
Lubahn et al. (2011)	Bagnoli 8 Delsys	NS; skin debrided and cleansed	NS	NS	NS	1000	Band pass 20 - 450 High-pass filtered (Butterworth, 4^{th} order, 30Hz) Low-pass filtered (Butterworth, 4^{th} order, 6Hz)	960	NS	Integrated activity over the duration of the exercise
MacAskill et al. (2014)	16 channel Motion Lab	15 mm diameter; skin shaved and scrubbed	20	1M	90	50	Band pass 20 – 450 RMS smoothing (50ms)	4000	Full	Integrated EMG activity across a repetition.
Mauntel et al. (2013)	Delsys Bagnoli	Skin shaved, abraded and cleaned	NS	NS	NS	NS	Band pass 10 - 350 Low-pass (Butterworth, 4^{th} order, 14.5 Hz) Notch filtered 59,5-60.5 Hz RMS smoothed (25ms)	1000	Full	Average activity from the descent phase

Table 4. *Electromyographic technical aspects of included studies. (continued)*

McBeth et al. (2012)	16 channel Run Technologies	NS; skin debrided and cleansed	26	NS	NS	1000	Band pass 10 - 499 (Butterworth filter) RMS smoothed (20ms)	1000	Full	Average activity from 3 trials
Monteiro et al. (2017)	8 channel EMG system Brazil 16 bit resolution	10 mm diameter; skin shaved, abraded and cleaned.	20	NS	NS	NS	Band pass 10 - 500	NS	Full	Average (RMS) of the concentric phase
Morimoto et al. (2018)	Biolog DL 5000	NS	NS	NS	NS	NS	Band pass 20 – 500	1000	Full	Average (RMS)
Noh et al. (2012)	Delsys Trigno	NS; skin rubbed and cleaned	NS	NS	NS	NS	Band pass 20 – 450	1000	Full	Average (RMS) of three trials
Oliver et al. (2010)	Noraxon myopic 1400L 8 channel	NS; skin cleansed and debrided	25	NS	NS	NS	Band pass 20-350 RMS smoothed (100ms) Notch filtered: 59.5Hz – 60.5Hz	1000	Full	Average EMG activity
Oliver & Stone (2016)	Delsys Bagnoli 8 channel	NS; skin shaved, abraded and cleaned	10	NS	NS	NS	RMS smoothed (100ms)	1000	Full	Average EMG activity
O'Sullivan et al. (2013)	Motionlab system MA-300 multichannel	144 mm^2; skin cleansed, abraded and shaved	18	NS	NS	2000	RMS smoothed (150ms)	1000	Full	Average (RMS) per trial
O'Sullivan et al. (2010)	Motionlab system MA-300 multichannel	144 mm^2; skin cleansed and debrided	18	NS	>100 @ 60 Hz	2000	Band-pass 5-500 RMS smoothed (150ms)	1250	Full	Average (RMS) per trial
Petrofsky et al. (2005)	12 bit A-D card	NS	20	NS	NS	5000	RMS	2000	Full	Average over a 1 second period
Philippon et al. (2011)	Delsys Bagnoli	.07 mm fine-wire	NS	>10M	>84	NS	RMS (50ms) Low pass 10 Hz	1200	Full	Average and peak amplitude
Selkowitz et al. (2013)	Motionlab system MA-300 multichannel 16 channel	50 µm fine wire	NS	> 1M	>110 @ 65 Hz	1.2 k	Band pass 35 - 750 (Butterworth) RMS smoothing (75ms)	1560	Full	Average activity for each repetition
Sidorkewicz et al. (2014)	AMT 8 Bortec 16 Bit converter	NS; skin shaved, rubbed and cleaned	30	10G	115 @ 60 Hz	NS	Band pass 10 – 500 Low-pass (Butterworth 2nd order, 3 Hz)	2160	Full	Peak amplitude
Sinsurin et al. (2015)	Noraxon Myosystem	NS; skin shaved, abraded and cleaned	20	10k	NS	NS	Bandpass 20 – 450 (Butterworth)	1500	Full	Average activity
Souza & Powers (2009)	Motion Control	Skin shaved, abraded and cleaned.	NS	NS	NS	2000	Band pass 35-500 Notch filter: 60Hz Moving average smoothing (75ms)	1560	Full	Average activity
Webster & Gribble (2013)	Noraxon 2000 telemyer system.	38x28 mm; skin shaved, abraded and cleaned	NS	100m	>100	NS	RMS smoothing (50ms) Butterworth 3rd order filter	1000	Full	Average activity over 0.4 secs surrounding maximum excursion
Willcox & Burden (2013)	Delsys	10x1 mm; skin shaved and cleaned	10	100M	> 80	NS	Band pass 20 – 500 RMS smoothing (150ms window, 62ms overlap)	1080	Full	Average activity per repetition
Youdas et al. (2012)	Delsys Bagnoli	41x20x5 mm; skin shaved and cleaned.	10	10^{15}	92 @ 60 Hz	100-10000	Band pass 20 – 450 RMS smoothing (125ms)	1000	Full	Peak activity
Youdas et al (2014)	Delsys Bagnoli 16 bit A-D card	41x20x5 mm; skin abraded and cleaned	10	10^{15}	92 @ 60 Hz	100-10000	Band pass 20 – 450 (Butterworth 4th order)	1000	Full	Average activity of 500ms interval surrounding peak
Youdas et al. (2015)	Delsys Bagnoli 16 bit A-D card	41x20x5 mm; skin abraded and cleaned	10	10^{15}	92 @ 60 Hz	100-10000	Band pass 20 – 450 RMS smoothing (125ms)	1000	Full	Average activity of 400ms interval surrounding peak
Zeller et al. (2003)	NS	Skin shaved and cleansed.	NS	NS	NS	NS	Low pass filtered (Butterworth, 4th order 15Hz)	960	Full	Average activity

Key: A-D – analogue-digital conversion; cm – centimeters; EMG – electromyography; Hz – hertz; mm – millimeters; ms – milliseconds; NS – not stated; RMS – root mean square; secs – seconds; µs – microseconds.

Gluteus minimus

Gluteus minimus activity was evaluated in one study[46] for three different variations of the hip hitch/pelvic drop exercise and found to generate high to very high activity (48-69% MVIC) for the anterior segment and very high activity (66-84% MVIC) for the posterior segment (Figures 3 and 4) (Table 6).

Standing hip abduction

Gluteus medius

Standing hip abduction was measured on the stance leg in four studies[46,59,72,82] (Table 5). For two studies that could be pooled together high activity levels (43.12 [95% CI 35.91, 51.79] % MVIC) were recorded for the middle GMed segment (Figure 7). Moderate to high activity (56% MVIC anterior, 30% MVIC middle and 41% MVIC posterior) was found in one study[46] that evaluated GMed segmental activity levels for isometric standing hip abduction.

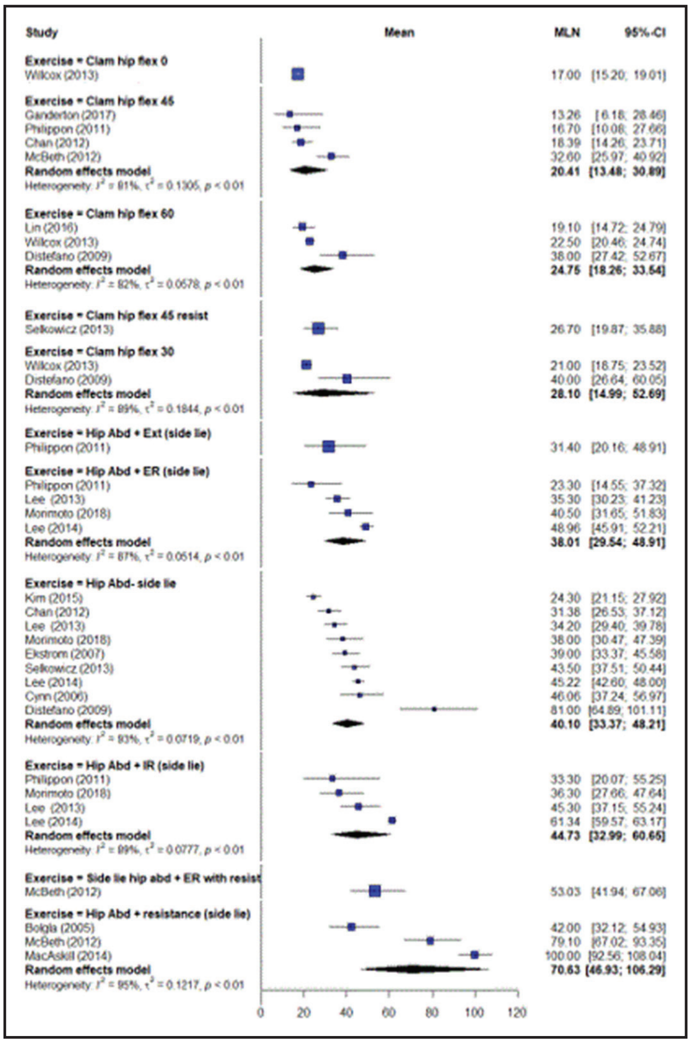

Figure 2. *Gluteus medius middle – side-lie clam and hip abduction exercises.*

Gluteus minimus

Gluteus minimus segmental activity levels were also recorded for isometric standing hip abduction, and high activity (55% MVIC anterior and 49% MVIC posterior) were found for both segments[46] (Figures 3 and 4) (Table 6).

Supine bridge

Gluteus medius

The single-leg bridge was investigated in seven single electrode GMed middle studies[66,68,71,78,97-99] (Table 5). For six studies that could be pooled together, high activity levels (41.27 [95% CI 33.98, 50.13] % MVIC were produced (Figure 12). The double leg bridge was evaluated in five studies[66,71,78,97,99] for middle GMed and when pooled together generated low activity levels (18.80 [13.83, 25.66] % MVIC) (Figure 12).

Gluteus minimus

The single leg bridge was measured in one study[47] and generated low activity (14% MVIC) in the anterior GMin segment and high activity (46% MVIC) for the posterior GMin segment (Figures 3 and 4) (Table 6).

DISCUSSION

The aim of this systematic review was to determine whether commonly evaluated rehabilitation exercises generate at least high activity levels in GMed and GMin segments. The results indicate that different variations of the hip hitch/pelvic drop exercise are the best options to generate at least high activity in all segments of GMed. To target the anterior GMed segment, additional options could include isometric standing hip abduction and the dip test. For the middle GMed segment at least high activity was generated by the single leg bridge; side-lying hip abduction with hip internal rotation; lateral step-up; resisted side-step; and standing hip abduction on stance or swing leg with added resistance. Another exercise option for the posterior GMed segment is isometric standing hip abduction.

For the GMin different variations of the hip hitch/pelvic drop exercise and isometric standing hip

Table 5. *Segmental mean gluteus medius activity levels (% MVIC) for exercises.*

Exercise category	Exercise	Muscle segment (middle unless indicated)	Low (0-20% MVIC)	Moderate (21-40% MVIC)	High (41-60% MVIC)	Very High (> 60% MVIC)
Side-lie	Hip abduction			39[71]; 34[75]; 37[58]; 29-31[73]; 38[79]; 25-46[74]; 24[56]	42R[72]; 45[76]; 44[78]	63[68]; 8[70]; 79R[69]; 100R[77]
	Hip abduction + ER			35[75]; 37[58]; 23[66]	53R[69]; 41[79]; 49[76]	
	Hip abduction + IR			36[79]; 33[66]	45[75]; 49[58]	62[76]
	Hip abduction + Ext			31[66]		
	Clam hip flex 0°		13-17[80]; 17[66]			
	Clam hip flex 30°		13-21[80]	40[70]; 27[58]		
	Clam hip flex 45°	Anterior	3[46]			
		Middle	13[46]; 16-18[73]; 17[66]	33[69]; 27R[78]; 36[58]	47[68];	
		Posterior		23[46]		
	Clam hip flex 60°		19[81]	36[58]; 38[70]; 18-23[80]		
Squat	Single leg squat	Anterior				90[52]
		Middle	18[81]	36[83]; 30[64]; 30-31[65]; 23[84]; 24[85]; 20-27[88]; 33-37[86]	59U[67]; 48[67]; 41-77[87]	82[68]; 64[70]; 77[48]; 66[57]; 92[52]
		Posterior				87[52]
	Single leg squat + Abd	Anterior	19[62]			
		Middle		27[62]	42-46[111]	
		Posterior		33[62]		
	Single leg squat + Add	Anterior			42[62]	
		Middle		31[62]		
		Posterior		22[62]		
	Single leg wall squat	Anterior	13[63]			
		Middle		25[63]; 27[84]; 22-32[88]	52[83]	
		Posterior		35[63]		
	Single leg wall squat + Abd	Anterior		29[62]		
		Middle		33[62]		
		Posterior			44[62]	
	Single leg wall squat + Add	Anterior	16[62]			
		Middle		21[62]		
		Posterior		28[62]		
	Single leg skater squat				60[68]	
	Single leg squat + rotation					66[50]
	Squat		10[78]; 9-12R[61]	26-33[54]; 21[57]; 22-28[89]		
	Wall squat		9-10[111]			
	Squat + Abd			24[57]	47-52[54]	
	Squat + Add				59[54]	
Step	Lateral step-up			38[83]; 39[94]	60[68];	63[77]
	Lateral step-up + IR				41[94]	
	Lateral step-up + ER			30[94]		
	Lateral step-down			21[84]; 19-25[88]		74[48]
	Lateral step	Anterior				
		Middle		24-35RS[53] ; 30RS[78]; 33-50RS[93]		
		Posterior		19-23RU[91]; 23-36RS[91]		
	Lateral step + IR				44-58RS[93]	
	Lateral step + ER			27-48RS[93]		
	Forward step-up		17[85]	29[49]; 30[78]	44[83]; 55[68]; 48[57]; 45MR[57]	62[77]
	Forward step-down		14[92]; 17[5]	23[84]; 20-22[49]; 28[51]; 21-27[85]; 19-27[88]		
	Forward step-up and over	Anterior				88[52]
		Middle	15-17[64]; 15-21[65]			85[52]
		Posterior				81[52]
	Retro step-up			37[83]		
Lunge	Forward lunge	Anterior			45RE[46]	
		Middle	18-19[64]; 12-25[65]; 12[92]; 19[78]; 15[95]; 8[81]	29[71]	42[70]	71RE[46]
		Posterior		28RE[46]		
	Transverse lunge				48[70]	68[50]
	Sideways lunge		13[92]	39[70]		
Standing	Hip hitch/ pelvic drop	Anterior		21[63]; 25[55]; 25[60]		69[46]; 80[52]
		Middle		28[63]; 23[55]; 38[78]	57[72]; 58[68]; 42[96]	66[46]; 88[52]
		Posterior		38[63]; 22[55]		74[46]; 88[52]
	Hip hitch/ pelvic drop + IR				42[96]	
	Hip hitch/ pelvic drop + ER			33[96]		
	Hip hitch/ pelvic drop + leg swing	Anterior				82[46]
		Middle				66[46]
		Posterior				72[46]
	Hip hitch/ pelvic drop + toe tap	Anterior				76[46]
		Middle			58[46]	
		Posterior			46[46]	
	Hip abduction	Anterior			56[46] I	
		Middle		30I[46]	42-46R[72]; 44[59]; 50R[82]	
		Posterior			41I[46]	
	Hip abduction (moving limb)			28-33[72]	53R[82]	64[59]
Supine	Single leg bridge			33-35[97]; 31[78]; 35[66]	40-42[99]; 55[68]; 47U[68]; 47[71]; 42-58[98]	
	Double leg bridge		17[97]; 15[78]; 11[66]	20-21[99]; 28[71];		

Key: Abd – abduction; Add – adduction; ER – hip external rotation; Ext – extension; Flex – flexion; IR – hip internal rotation; I – isometric exercise; MR – added medial resistance; R – added external resistance; RE – rearfoot elevated; RS – resisted squat posture; RU – resisted upright posture; U – unstable surface.

Table 6. *Segmental mean gluteus minimus activity levels (% MVIC) for exercises.*						
Exercise category	Exercise	Muscle segment	Low (0-20% MVIC)	Moderate (21-40% MVIC)	High (41-60% MVIC)	Very High (> 60% MVIC)
Side-lie	Hip abduction	Anterior		38[47]		
		Posterior			43[47]	
	Clam hip flex 45^0	Anterior	7[46]; 3[47]			
		Posterior	20[46]; 8[47]			
Squat	Single leg squat	Anterior		25[47]		
		Posterior			46[47]	
Lunge	Forward lunge	Anterior		21RE[46]		
		Posterior				66RE[46]
Standing	Hip hitch/pelvic drop	Anterior				69[46]
		Posterior				84[46]
	Hip hitch/pelvic drop + leg swing	Anterior			60[46]	
		Posterior				79[46]
	Hip hitch/pelvic drop + toe tap	Anterior			48[46]	
		Posterior				67[46]
	Hip abduction	Anterior			55I[46]	
		Posterior			49I[46]	
Supine	Single leg bridge	Anterior	14[47]			
		Posterior			46[47]	
Key: I – isometric exercise; RE – rear-foot elevated						

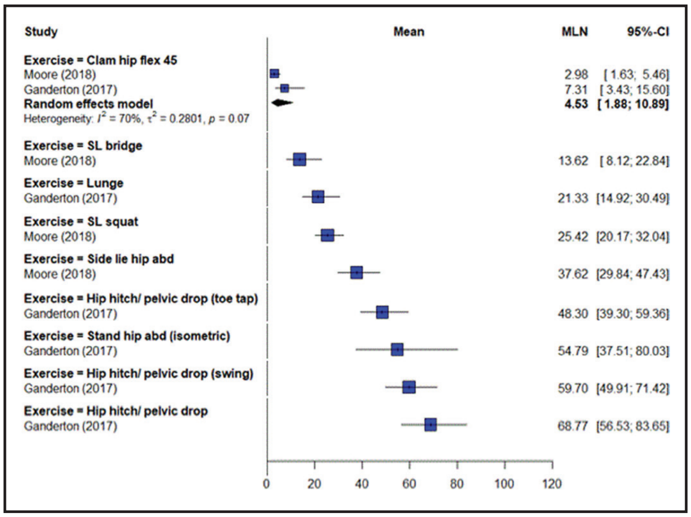

Figure 3. *Gluteus minimus anterior exercises.*

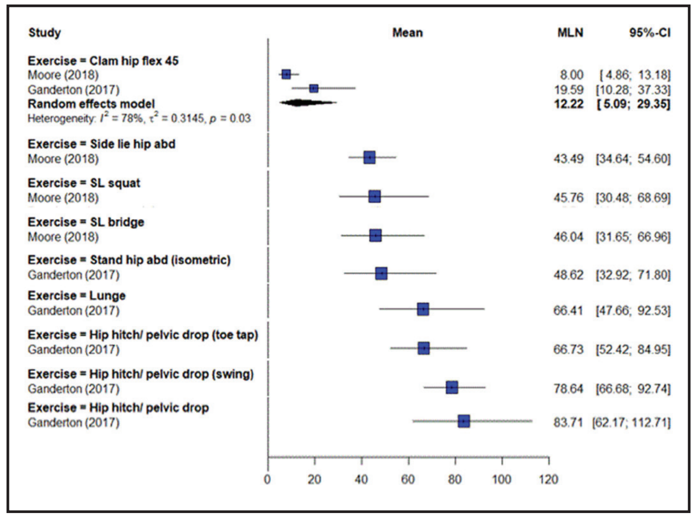

Figure 4. *Gluteus minimus posterior exercises.*

abduction were the best options to generate at least high activity in both segments. Additional exercises to target the posterior GMin segment included the dip test; single leg bridge; single leg squat; and side-lying hip abduction.

Single leg weight-bearing exercises appeared to generate at least moderate activity in all three segments of GMed. This is despite the wide methodological variations between studies for similar exercises and the relatively small number of studies that evaluated the separate GMed segments for different exercises. This highlights the functional role of GMed as a multi-planar hip and pelvic stabilizer in weight-bearing activities. Based on the large physiological cross-sectional area and favorable coronal plane moment arm,[100] GMed is well suited to maintaining pelvic and hip joint equilibrium during single-limb loading tasks.

The clam exercise appeared least favorable in terms of recruiting GMed muscle activity. With a relatively short anti-gravity lever arm to overcome, the clam recorded low activity in the anterior and middle segments, and moderate activity in the posterior segment. This perhaps reflects the biomechanical properties of GMed muscle segments, with the anterior segment having an internal rotation moment arm in the transverse plane, the middle segment a negligible rotation moment arm, and the posterior segment an external rotation moment arm.[100] The clam may potentially be useful in early rehabilitation for motor control and recruitment but unlikely to elicit sufficient activity

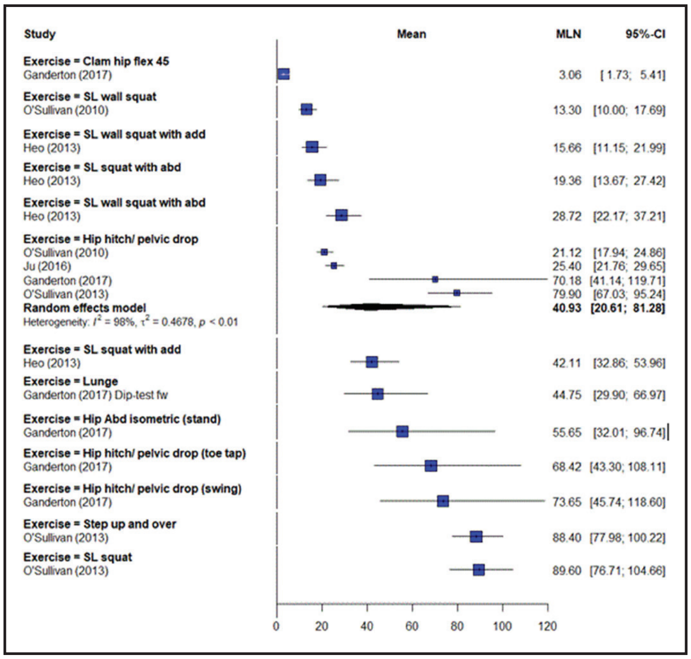

Figure 5. *Gluteus medius anterior exercises.*

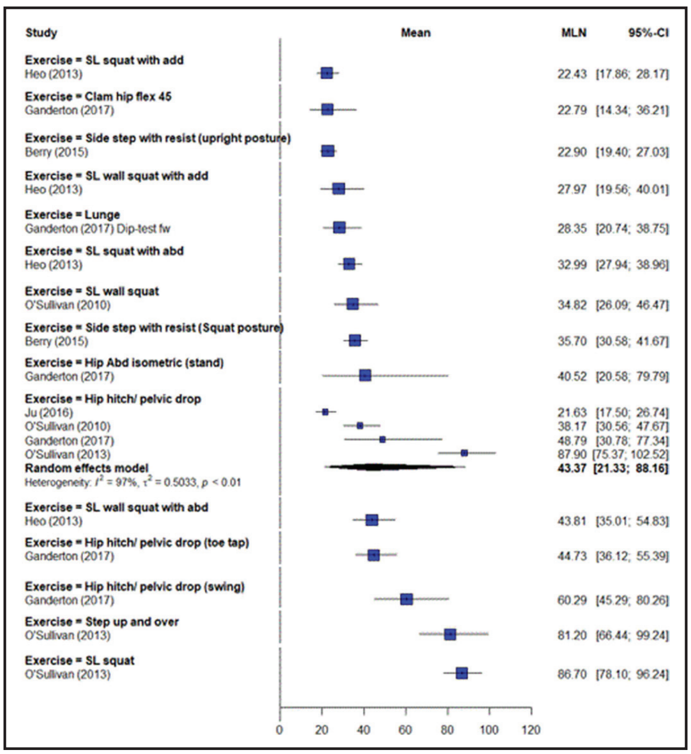

Figure 6. *Gluteus medius posterior exercises .*

for strengthening.[101] This is particularly the case for the anterior and middle segments.

Recruitment of posterior GMin with a wide variety of exercises appears more feasible than anterior

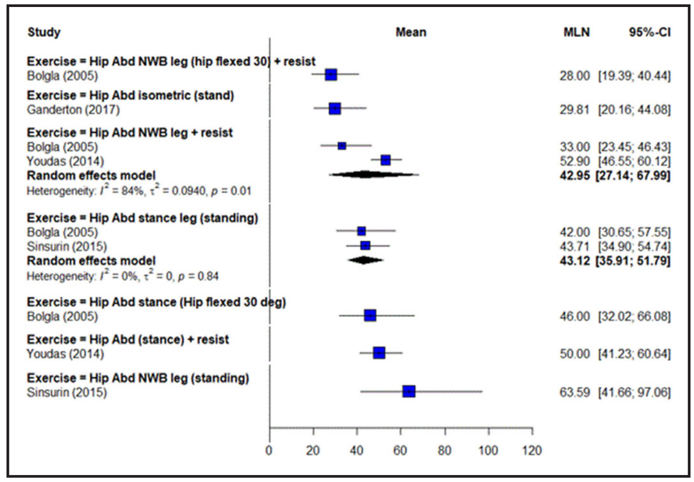

Figure 7. *Gluteus medius middle - standing hip abduction.*

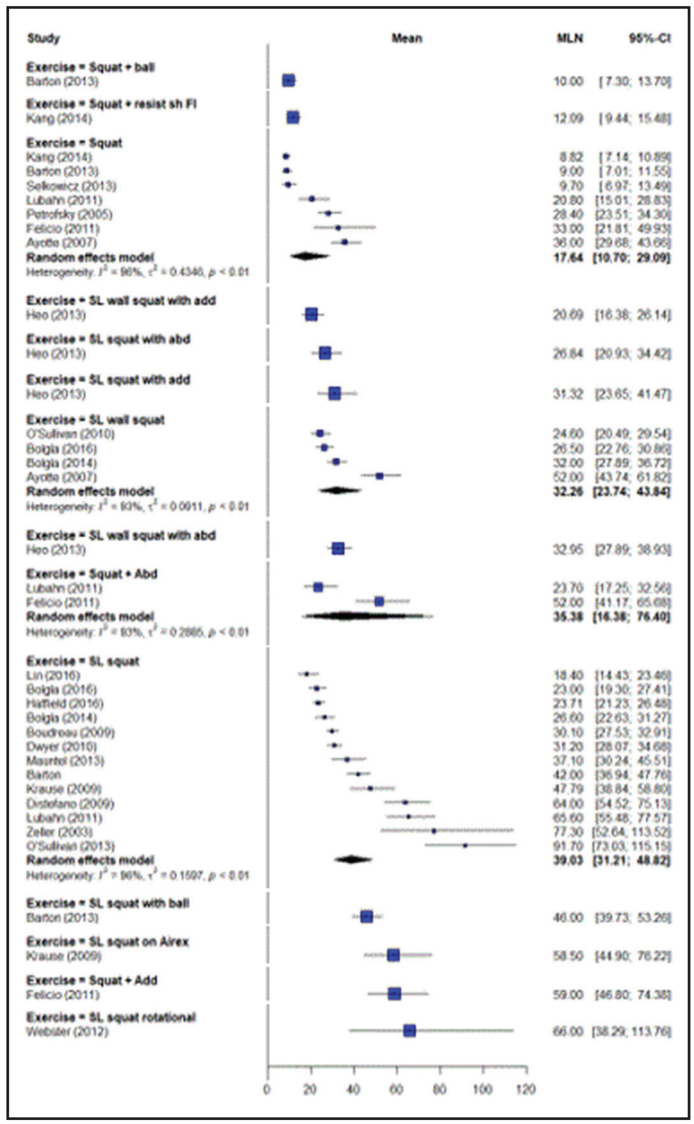

Figure 8. *Gluteus medius middle - squat exercises.*

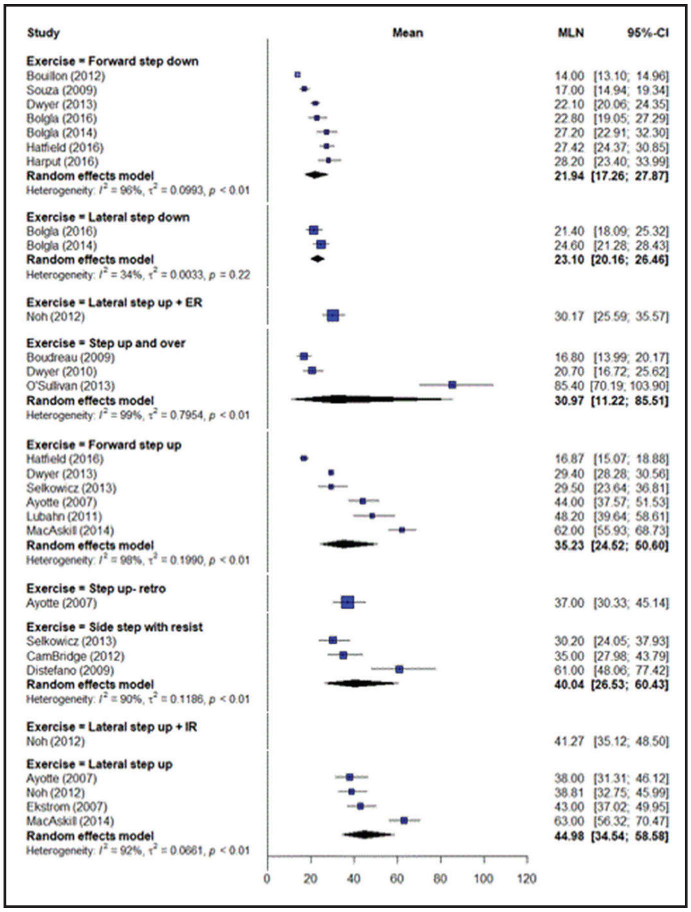

Figure 9. *Gluteus medius middle - step exercises.*

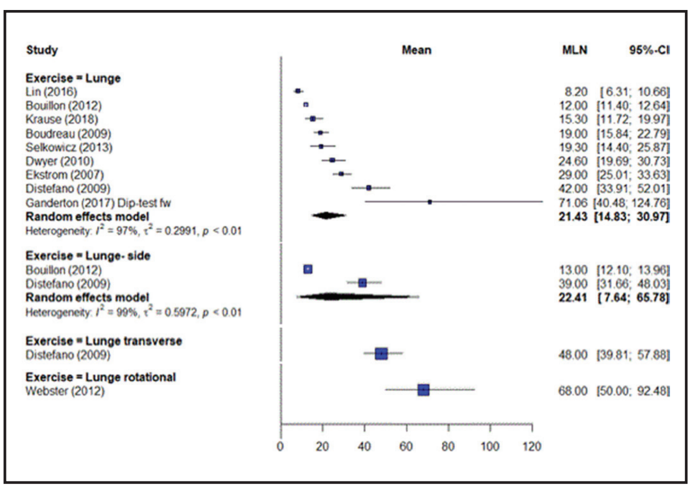

Figure 10. *Gluteus medius middle - lunge exercises.*

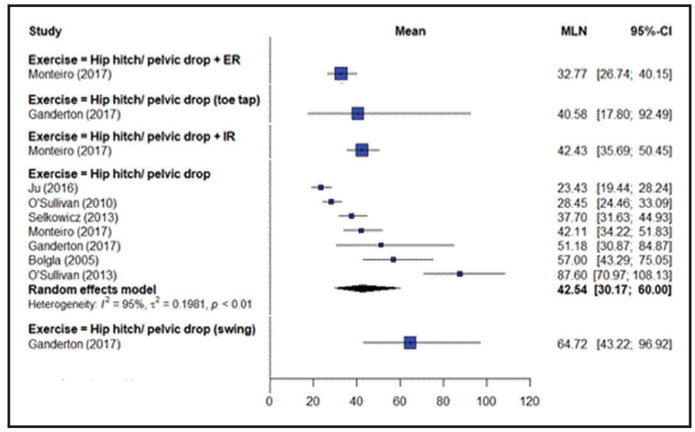

Figure 11. *Gluteus medius middle - hip hitch/pelvic drop exercises.*

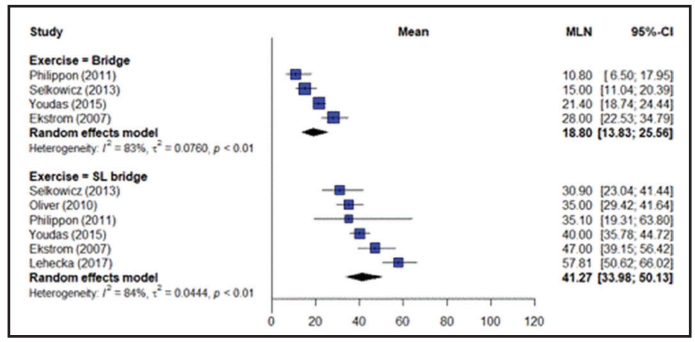

Figure 12. *Gluteus medius middle - bridge exercises.*

GMin. There are a broader range of exercises available for strengthening the posterior GMin with single leg weight-bearing exercises, and side-lying hip abduction potential options. In comparison, the anterior GMin functioning as an anterior hip capsule stabilizer, and prime hip abductor,[102] appears to be more difficult to target for strengthening compared to the posterior segment. For example, the single leg squat exercise is broadly useful for recruiting all segments of GMed as well as posterior GMin but may have less utility for anterior GMin (moderate level of activity). This might reflect the tendency of studies to include exercises with an external rotation bias. Since anterior GMin is highly active with internal rotation,[19] and has a favorable moment arm for internal rotation,[100] further research examining internal rotation-based exercises for anterior GMin highlight further options for recruiting this muscle segment. The clam exercise may not have great utility for GMin muscle strengthening. Both studies in this review showed similar results for the two GMin segments during the clam exercise with low activity generated.[46,47]

In the clinic, individual assessment is important to ensure that the most appropriate exercise strategy is prescribed to meet the client's functional requirements. Post-surgery or in the acute phases of an injury, some clients may be unable to perform weight-bearing exercises early in the rehabilitation process. Prescribing a suitable non-weight-bearing exercise such as side-lying hip abduction may overcome this barrier while still delivering a strengthening stimulus for the muscle segment being targeted. Exercises that did not generate high levels of activity[101] for a specific segment may still be beneficial in a progressive rehabilitation program as hypertrophy may not be the goal in the initial stages particularly if the client is deconditioned or in pain. Further to this, since most included studies contained healthy young participants performing rehabilitation exercises, the results from these studies may not be relevant to the elderly client or for the well-conditioned athlete. In both cases it is likely that the recommended exercises will need modifications to meet the individuals' functional goals. For example, the elderly client may need decreased loading strategies and less demanding forms of an exercise. In contrast, for the well-conditioned athlete to stimulate hypertrophy, an exercise may need added loading through weights or elastic resistance to meet that goal.[101]

Strength and limitations

From a summary of the results the authors were able to determine whether commonly evaluated therapeutic exercises specifically target the individual GMed and GMin segments effectively in generating at least high activity levels (>40% MVIC) considered essential for potential strengthening.[101] Through application of a stringent methodological process, an objective evaluation of current evidence to date was provided.

A limitation of this systematic review was that not all commonly evaluated therapeutic exercises included in this review have been evaluated for the different segments of GMed and GMin making it difficult to make recommendations for some exercises.

The recording of GMed muscle activity with surface electrodes has some drawbacks. Five included studies[46,52,55,62,63] investigated therapeutic exercises for the three individual GMed segments, with one study[46] using fine-wire electrodes positioned as per previously validated guidelines[103] to measure segmental activity levels. The use of surface electrodes to record activity in the posterior and anterior segments of GMed must be questioned due to the anatomical coverage by the tensor fascia lata and gluteus maximus muscles.[103] In fact, even recording GMed activity from the exposed portion of the muscle is subject to crosstalk from the gluteus maximus.[20] During exercises involving large ranges of movement, there may also be artefact associated with movement of the muscle relative to the recording electrodes.[104]

Other limitations of this review may be due to excluding studies that did not contain commonly evaluated therapeutic exercises or utilizing gym and/or custom-made equipment; and eliminating data for dynamic activities like jogging, hopping and walking. The original search strategy may have missed studies due to publication bias and not contacting experts for unpublished papers. Papers not published in peer-reviewed journals such as conference abstracts and theses were also excluded possibly missing potential data. This review only evaluated EMG activation levels and not muscle onset timing patterns or the balance of synergists and antagonists for a therapeutic exercise as may be considered in the clinical setting. Data for pathological populations were not considered in this review which makes it difficult to generalize to such populations.

CONCLUSION

The purpose of this review was to analyze studies that have evaluated segmental activity levels for the GMed and GMin with commonly evaluated therapeutic exercises to improve clinician knowledge of appropriate exercise prescription for targeted strengthening. With at least high activity levels necessary for potential strength gains this review found that despite wide methodological variations between studies, different variations of the hip hitch/pelvic drop exercise elicits activity in all GMed segments sufficiently in healthy individuals. The dip test and isometric standing hip abduction can also be used to strengthen the anterior GMed segment, while isometric standing hip abduction can be used for the posterior GMed segment. For the middle GMed segment the single leg bridge; side-lying hip abduction with hip internal rotation; lateral step-up; standing hip abduction on stance or swing leg with added resistance; and resisted side-step were the best options for strengthening. Isometric standing hip abduction and different variations of the hip hitch/pelvic drop exercise can be prescribed for strengthening both GMin segments while side-lying hip abduction, the dip test, single leg bridge and single leg squat can also be used for targeting the posterior GMin segment.

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