AMNESIA GLÚTEA

BY MARIO NEGRETE [MASTER TRAINER.AUT]

¿POR QUÉ SE DA? CÓMO LO ACTIVAMOS?

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AMNESIA GLÚTEA

TÉRMINO ACUÑADO POR

STUART McGILL

PROFESOR DE BIOMECÁNICA UNIVERSIDAD DE WATERLOO

POR QUÉ SE DA?

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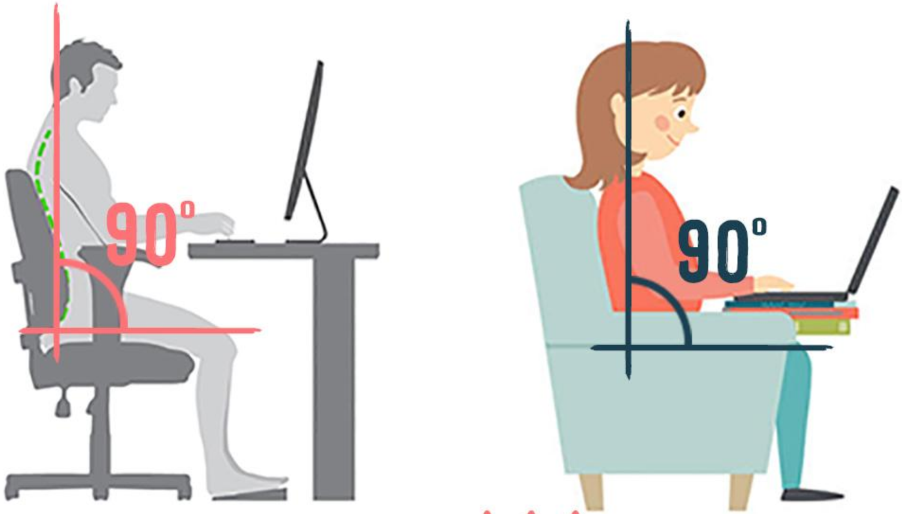


AL PERMANERCER SENTADOS DURANTE TANTO TIEMPO NUESTROS FLEXORES DE CADERA ESTÁN SOBREACTIVADOS LO QUE PRODUCE UN "ACORTAMIENTO" DE ESTA MUSCULATURA ASÍ COMO UNA INHIBICIÓN (FALTA DE ACTIVACIÓN) EN EL PRINCIPAL EXTENSOR DE LA CADERA, EL GLÚTEO, PARA QUE ESTA TENSIÓN SE PUEDA MANTENER.

FLEXORES DE CADERA

PRINCIPALES

PSOASILÍACO

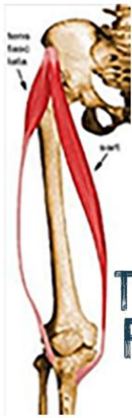
SARTORIO

RECTO ANTERIOR

COLABORADORES

PECTINIO

ADUCTOR MEDIANO



TENSOR FASCIA LATA

RECTO INTERNO

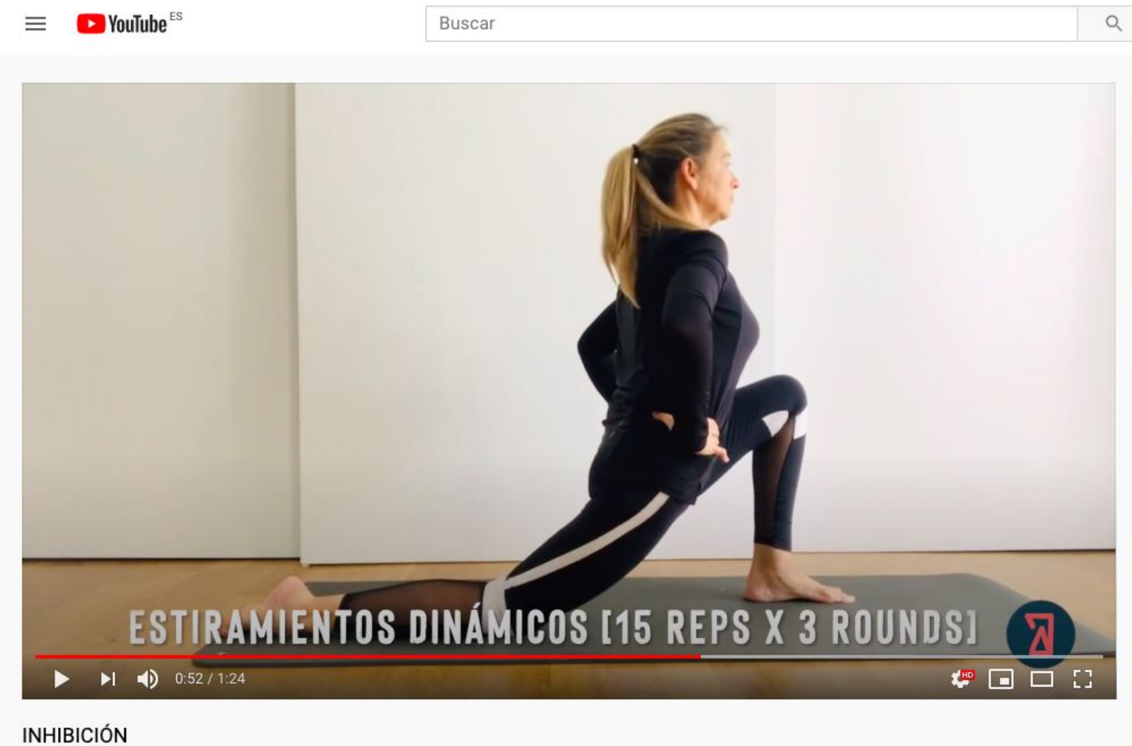
AUT. 2 PROPUESTAS

INHIBICIÓN & ACTIVACIÓN

A TRAVÉS DE ESTA PROPUESTA DE EJERCICIOS LO PRIMERO QUE VAMOS A HACER ES ELIMINAR ESTA TENSIÓN EN LOS FLEXORES DE CADERA, Y UNA VEZ ESTA MUSUCLATURA ESTÉ ELONGADA PASAREMOS A UNA SERIE DE EJERCICIOS PARA ACTIVAR Y DESPERTAR LA ZONA GLÚTEA.

INHIBICIÓN

VÍDEO INHIBICIÓN DE FLEXORES



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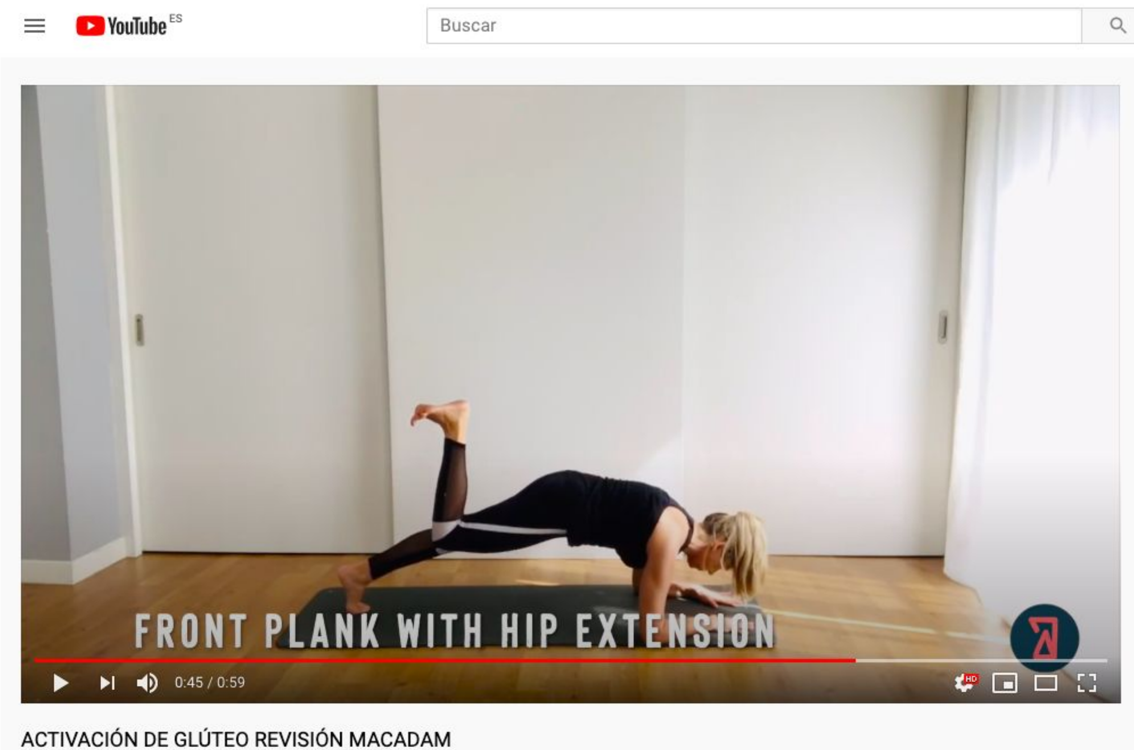
VÍDEO ACTIVACIÓN DE GLÚTEO



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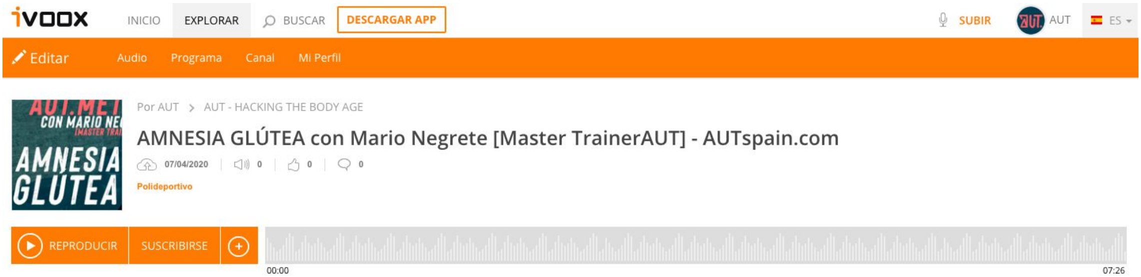
AUT. AMNESIA GLÚTEA
BY MARIO NEGRETE [MASTER TRAINER.AUT]

PODCAST-ENTREVISTA 7MIN



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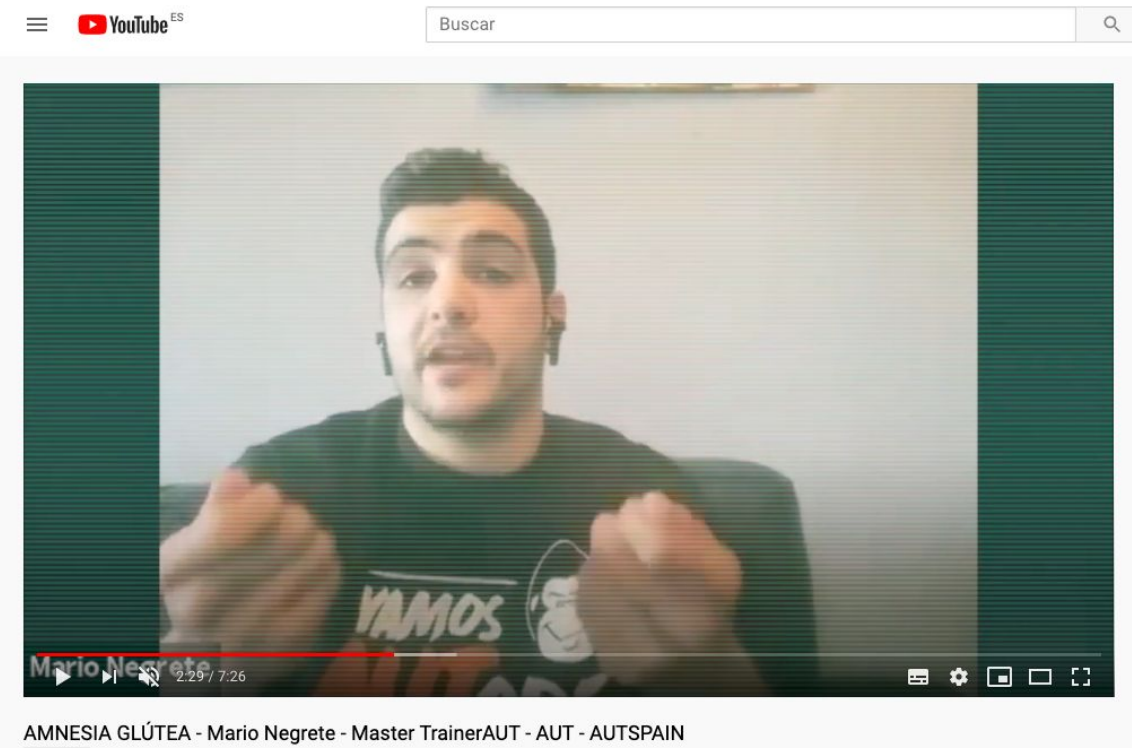
VIDEO-ENTREVISTA 7MIN



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by Mario Negrete [MASTER TRAINER.AUT]

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BMJ Open Sport & Exercise Medicine

Effect of a gluteal activation warm-up on explosive exercise performance

Matt Parr,[1,2] Phil DB Price,[1] Daniel J Cleather[1]

Parr 2017

Efectos de la activación de glúteo en la mejora de movimientos explosivos.

Conclusión

Este estudio sugiere que una activación previa de los glúteos antes de realizar movimientos explosivos mejora el rendimiento en ellos.

IJSPT

ORIGINAL RESEARCH

ELECTROMYOGRAPHIC ANALYSIS OF GLUTEUS MEDIUS AND GLUTEUS MAXIMUS DURING REHABILITATION EXERCISES

Kristen Boren, DPT[1]
Cara Conrey, DPT[1]
Jennifer Le Coguic, DPT[1]
Lindsey Paprocki, DPT[1]
Michael Voight, PT, DHSc, SCS, OCS, ATC, CSCS[1]
T. Kevin Robinson, PT, DSc, OCS[1]

Kristen boren et al 2011

Análisis electromiográfico de glúteo mayor y glúteo medio durante ejercicios de rehabilitación.

Conclusiones

Como aplicación práctica de esta revisión podemos observar en este estudio que el ejercicio de plancha frontal+extensión de cadera a 90° es el ejercicio de los analizados más demandante para el glúteo mayor.

IJSPT

SYSTEMATIC REVIEW

AN EXAMINATION OF THE GLUTEAL MUSCLE ACTIVITY ASSOCIATED WITH DYNAMIC HIP ABDUCTION AND HIP EXTERNAL ROTATION EXERCISE: A SYSTEMATIC REVIEW

Paul Macadam, BSc[1]
John Cronin, PhD[1,2]
Bret Contreras, MA[1]

Paul Macadam et al 2015

Revisión sobre que ejercicios activan más el glúteo mayor y medio (a través de electromiografía) de pie,tumbado de lado y sentado

Conclusiones:ejercicios más demandantes

- **De pie; Glúteo mayor**
  Step up lateral
- **De pie; Glúteo medio**
  Abducción lateral de cadera con banda en tobillo para glúteo medio
- **Tumbado de lado; Más activación tanto glúteo mayor como glúteo medio**
  Plancha lateral con elevación de pierna superior
- **Sentado; Más activación tanto glúteo mayor como glúteo medio**
  Abduciones sentadas en máquina

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BMJ Open Sport & Exercise Medicine

Effect of a gluteal activation warm-up on explosive exercise performance

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ABSTRACT

Objectives To evaluate the effect of a gluteal activation warm-up on the performance of an explosive exercise (the high hang pull (HHP)).

Methods Seventeen professional rugby union players performed one set of three HHPs (with 80% of their one repetition maximum load) following both a control and activation warm-up. Peak electrical activity of the gluteus maximus and medius was quantified using electromyography (EMG). In addition, the kinematics and kinetics of nine players was also recorded using force plate and motion capture technology. These data were analysed using a previously described musculoskeletal model of the right lower limb in order to provide estimates of the muscular force expressed during the movement.

Results The mean peak EMG activity of the gluteus maximus was significantly lower following the activation warm-up as compared with the control ($p<0.05$, effect size $d=0.30$). There were no significant differences in the mean peak estimated forces in gluteus maximus and medius, the quadriceps or hamstrings ($p=0.053$), although there was a trend towards increased force in gluteus maximus and hamstrings following the activation warm-up. There were no differences between the ground reaction forces following the two warm-ups.

Conclusion This study suggests that a gluteal activation warm-up may facilitate recruitment of the gluteal musculature by potentiating the glutes in such a way that a smaller neural drive evokes the same or greater force production during movement. This could in turn potentially improve movement quality.

What are the key findings?

- Seventeen elite rugby union players performed an Olympic weightlifting exercise after both a control and a gluteal activation warm-up.
- There were no differences in the ground reaction forces after the two warm-ups. There was a decrease in electromyography following the activation warm-up, but in contrast there were clear trends that were consistent with an increased recruitment of the glutes and hamstrings.
- These findings support the clinical practice of prescribing gluteal activation exercises to facilitate recruitment of the glutes during activity.
- In addition, this study supports the notion that the mechanism of this improved recruitment is through a potentiation of the glutes such that increased force is expressed for a given neural impulse.

INTRODUCTION

The purpose of a warm-up is to prepare the body for activity and in particular to promote optimal performance and decrease injury risk. One aspect of a modern warm-up is often a battery of 'activation' exercises (often therapeutic exercises) which are thought to promote the recruitment of specific musculature.[1] The rationale behind this is again twofold—improved activation of key musculature might improve both the kinematics of movement (reducing injury risk) and the ultimate performance outcome. One common candidate for such activation protocols is the gluteal musculature. This is in part because the glutes are one of the main contributors to force production in lower limb extension,[2–4] and in part because weakness or altered activity of the glutes is sometimes implicated in a range of musculoskeletal complaints including lower back pain[5 6] and anterior knee pain.[7–10]

A number of previous groups have investigated the effect of therapeutic gluteal activation exercise on athletic performance both acutely[11–14] and over a short training period.[15] The results of this research have been equivocal however; some authors reported modest increases in performance outcome,[11–13] whereas others found no difference.[14 15] One reason for these equivocal results is that the majority of the previous research has only quantified performance outcome (eg, height jumped, power output) and has not sought to evaluate changes in kinematics, electromyography (EMG) or muscular forces.

The purpose of this study was therefore to perform the first comprehensive investigation of the effect of a gluteal activation warm-up on subsequent explosive activity, incorporating measures of performance outcome, but also kinematics and electromyography (EMG). A unique aspect of the research was the incorporation of a state-of-the-art musculoskeletal model of the lower limb[16] which permits the estimation of the actual muscle forces expressed during movement. We hypothesised that the gluteal activation warm-up would facilitate increased force expression in the glutes during movement.

METHODS

Experimental approach

Nine professional rugby players (FB group) performed a high hang pull (HHP) after both a control and an activation warm-up (cross-over design). The kinetics and kinematics of their movement was input into a musculoskeletal model (FreeBody[16]) to calculate estimates of the muscular forces during the movement while EMG was used to simultaneously quantify the electrical activity of the gluteus maximus and medius. An additional eight professional rugby players performed the same protocol but were monitored using EMG alone (thus giving a cohort of 17 players who were analysed using EMG; ALL group).

Subject characteristics

Seventeen elite male Premiership rugby union players took part in this study (previous research that has found significant differences in performance outcome after a gluteal activation warm-up had group sizes between 10 and 22 subjects[11–13]). There were no differences between the complete cohort and the subcohort who were analysed using FreeBody (table 1). The study was approved by the ethical review board of St Mary's University and all subjects gave informed written consent prior to testing.

Procedure

Subjects performed the trial on a day without any scheduled club training. On arrival, EMG electrodes and retroreflective markers were placed on the subjects (subjects wore tight fitting clothing). Markers and electrodes remained in situ until the completion of the final test. Following electrode and marker placement, the subjects completed the control warm-up shown in table 2. Next, the subjects had a 1 min rest period before performing a set of three HHPs using a load equal to 80% of their one repetition maximum (1RM; the players' 1RMs were calculated by the club's strength and conditioning coach based on their previous test scores). Subjects stood with their right foot centred on the force plate (figure 1A). Kinematic, kinetic and EMG data were collected simultaneously as described below.

Following the control test, subjects then rested for 20 min. They then repeated an identical protocol as for the first test, except the control warm-up was replaced with the activation warm-up illustrated in table 2. Finally, the subjects had a further 20 min rest before completing maximum voluntary contraction (MVC) testing using previously established methods.[17] (In brief, the subjects extended the hip maximally while lying prone to maximally contract gluteus maximus and abducted the hip maximally from a side lying position to contract gluteus medius. In both instances, manual resistance was provided by one of the investigators.)

Instrumentation

Motion capture

The positions of 18 retroreflective markers (attached with adhesive spray to the anatomical landmarks described in our previous work[16]) were recorded at 200 Hz using an 11 camera Vicon motion capture system (Vicon MX system, Vicon Motion Systems, Oxford, UK). The ground reaction force was recorded simultaneously at 1000 Hz using a Kistler force plate (Kistler Type 9286AA, Kistler Instrumente, Winterthur, Switzerland) and synchronised with the kinematic data using the Vicon system.

Electromyography

EMG data were recorded from the gluteus maximus and medius at 1000 Hz using a Biopac MP150 data acquisition system (BIOPAC Systems, California, USA). The EMG electrode sites were shaved and then cleaned with alcohol wipes. EMG electrodes were placed following the guidelines of the Surface ElectroMyoGraphy for the Non-Invasive Assessment of Muscles project (SENIAM project; www.seniam.org). In particular, the gluteus maximus markers were placed 2 cm apart halfway between the line from the second sacral vertebrae and the greater trochanter of the femur, and the gluteus medius markers were placed 2 cm apart and halfway along the line connecting the iliac crest to the greater trochanter.

Data analysis

Musculoskeletal modelling approach

We employed a publicly available musculoskeletal model of the lower limb (FreeBody; www.msksoftware.org.uk) in order to calculate estimates of the lower limb forces expressed during the HHP. The FreeBody model is described in great detail in a number of separate publications which catalogue its development,[18–22] the public version used in this study[16] and the validation and verification of the model,[23 24] and so only a brief description of the analysis approach is provided here.

FreeBody represents the right lower limb as a three-dimensional linked chain of five rigid segments representing the foot, calf, thigh, patella and pelvis where the location and orientation of each segment

Table 1 Subject characteristics

	ALL group	FB group
No. of subjects	17	9
Age (years)	26.0 (±3.9)	24.7 (±3.5)
Height (m)	1.868 (±0.067)	1.856 (±0.070)
Body mass (kg)	103.3 (±10.4)	101.8 (±9.6)
1RM HHP (kg)	109.1 (±10.7)	109.4 (±9.7)

1RM, one repetition maximum; HHP, hang pull from the high hang.

are calculated from the motion capture data. The geometry of the musculoskeletal system is then calculated based on the posture of the model using data taken from the cadaver studies of Klein Horsman and colleagues.[25] The equations of motion of the lower limb are posed in the global coordinate system using the wrench and quaternion notation of Dumas and colleagues[26] and are parameterised on a frame by frame basis using the musculoskeletal geometry, segment kinematics, segment anthropometry[27] and the force plate data. For each frame, this yields a system of 22 equations of motion with 193 unknown variables (muscle, ligament and joint contact forces), that is, an indeterminate system for which there are generally many possible solutions. In order to solve the equations of motion, the solution space is first narrowed by applying constraints based on the physiology of the musculoskeletal system (eg, muscles can only pull not push). The most physiologically likely solution is then selected using an optimisation approach. Specifically, the solution which minimises the sum of the muscle stresses and normalised ligament forces raised to the third power (equation 1[19 28 29]) is found using the fmincon function of MATLAB (V.2016b; Mathworks, Natick, Massachusetts, USA) for each frame individually.

$$\min_{F_i,\ L_i} J = \sum_{i=1}^{163}\left(\frac{F_i}{Fmax_i}\right)^3 + \sum_{i=1}^{14}\left(\frac{L_i}{Lmax_i}\right)^3 \qquad (1)$$

where F_i is the predicted force in the ith muscle; $Fmax_i$ is the maximum force capability of the ith muscle; L_i is the predicted force in the ith ligament; $Lmax_i$ is the failure limit of the ith ligament.

EMG analysis

EMG amplitude data were collected, rectified and smoothed to an epoch of 50 ms via the average over samples algorithm[30 31] using the Acqknowledge data acquisition and analysis software (BIOPAC Systems, 42 Aero Camino Goleta, CA 93117, USA). The smoothed EMG data were then normalised against the MVCs.

Statistical analysis

The performance of each repetition of the HHP was normalised by reference to the position of the marker on the right anterior iliac spine—times $t_0=0$ and $t_1=1$ were defined to be when the vertical displacement of the marker was at its smallest and greatest, respectively. The normalised values were then interpolated using the spline function of MATLAB to find values at regular intervals of 0.01 between $t=-1.0$ and $t=1.02$. These values were then combined to produce mean composite curves for each time series, for each subject and each trial and then for the overall means for control and activation trials.

Peak values of the ground reaction force, muscle force estimates and joint angles were identified from the mean curves of each subject and differences between warm-ups were assessed with a multivariate repeated measures analysis of variance (ANOVA) in IBM SPSS Statistics V.22.0 (International Business Machines Corporation; alpha set to $p<0.05$ a

Table 2 Control and activation warm-ups

Exercise	Control warm-up	Activation warm-up
Stationary bike	3 min	3 min
Inch worm	2 sets of 8	1 set of 6
Bodyweight squat	2 sets of 8	1 set of 6
Leg swing	2 sets of 5 each leg	1 set of 6 each leg
Lunge	2 sets of 4 each leg	–
Press up	2 sets of 8	–
Prone plank with hip extension (figure 1B)	–	1 set of 6 each leg*
Side plank with hip extension	–	1 set of 6 each leg*
Single leg squat	–	1 set of 3 each leg

*The planks involved a 2 s hold of position at the top for each repetition.

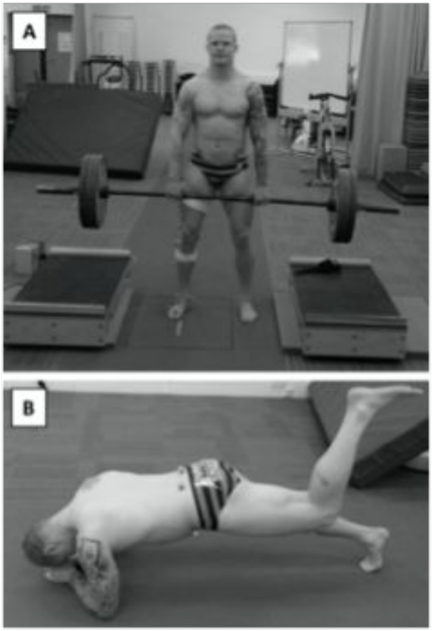

Figure 1 Illustrative images of a typical subject during a testing session. (A) Subject immediately prior to performing a high hang pull and (B) subject performing an activation exercise (prone plank with hip extension).

priori). The mean peak values of the normalised EMG signals and the baseline EMG signals (ie, the signal when the subject was holding the bar prior to the HHP) were found for each subject and trial. A two-factor repeated measures ANOVA was used to test for differences in this data ($p<0.05$). Finally, Cohen's d was calculated as a measure of effect size.

RESULTS

There were no differences in the ground reaction forces between control and activation trials (figure 2). Similarly, there were no statistically significant differences in hip or knee joint angles (figure 3), although the effect sizes of some of the differences in the peak non-sagittal plane angles were moderate to moderately large. In particular, during the activation trial, subjects' hips were more externally rotated ($d=0.75$, $p=0.12$), whereas their knees were in a less varus position ($d=0.54$, $p=0.15$).

The estimated muscle forces for the two trials are depicted in figure 2. There were no significant differences in the peak estimated muscle forces between the two trials ($p=0.053$). The effect sizes of the increase in peak hamstring ($d=0.68$, $p=0.07$) and gluteus maximus forces ($d=0.76$, $p=0.05$) were moderately large, whereas the effect size of the increase in peak gluteus medius ($d=0.46$, $p=0.26$) and quadriceps ($d=0.12$, $p=0.81$) forces were smaller.

There were no statistically significant differences in the baseline EMG activity of either gluteus maximus or medius (figure 4). There was a trend for the mean peak EMG activity during the HHP to decrease from the control to the activation trial. This decrease was statistically significant for gluteus maximus when the cohort was considered as a whole (effect sizes of $d=0.30$ and $d=0.20$ for ALL and FB, respectively) and for gluteus medius when considering just the group that was analysed using FreeBody (effect sizes of $d=0.28$ and $d=0.49$ for ALL and FB, respectively).

DISCUSSION

The effect of gluteal activation warm-up on performance of the HHP

In this study, we sought to explore the effect of a gluteal activation warm-up on the performance of an explosive exercise (the HHP). The major findings of our study are as follows. First, there was no effect of the activation warm-up on the performance outcome (ie, there were no differences in the ground reaction forces). Second, there were no statistically significant differences in the kinematics of the HHP between the two warm-ups and the sagittal plane kinematics were markedly similar. However, the effect sizes of the peak differences in knee varus and external hip rotation were moderate and moderately large, respectively. Third, there were no significant differences in the peak estimated muscle forces; however, there was a trend for increased hamstring and gluteus maximus forces after the activation warm-up and the effect sizes of the differences in peak hamstring and gluteus maximus forces were moderately large. Finally, there were some statistically significant decreases in the EMG of the gluteal musculature after the activation warm-up of small to moderate effect size.

The clinical premise for performing gluteal activation exercises as part of a warm-up is that this will facilitate the use of the gluteal muscle group during activity. Despite the relatively small number of statistically significant differences found in this study, this research does tend to support this premise. In particular, the trends found among the muscle force estimates and the non-sagittal plane kinematics are consistent with the common clinical understanding of the impact of greater gluteal activation. That is, there was a greater external rotation of the hip that was commensurate with an increased force production by the glutes and that the knee was closer to a neutral alignment. In addition, the differences in muscle force estimates did approach significance ($p=0.053$), and the effect sizes of the key differences in muscle force estimates and non-

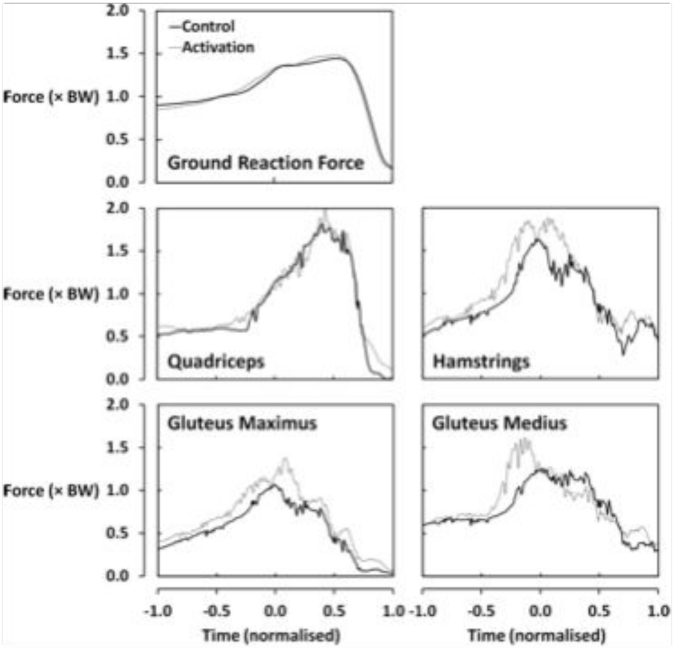

Figure 2 Ground reaction forces and estimated muscle forces during performance of a high hang pull after both a control and an activation warm-up (as a multiple of body weight (BW)).

sagittal plane kinematics were moderately large. Taken as a whole, these results do tend to suggest that a gluteal activation warm-up can change the relative muscular involvement within an activity and that this can have a positive impact on the posture of the lower limb.

In contrast with some of the previous literature,[11–15] this study did not demonstrate any change in the performance outcome after activation warm-up. One reason for this may be that previous authors have been somewhat overeager to support the efficacy (and use) of gluteal activation warm-ups and have overstated the meaning of their results. For instance, Crow and colleagues[11] argued that explosive power output was enhanced by an activation warm-up based on a small (effect size=0.233) but statistically significant increase in peak power output. This is especially bold given that an increase in peak power output does not necessarily mean there was an increase in jump height (jump heights were not reported). Similarly, Comyns and colleagues[12] reported that a gluteal warm-up can enhance force production based on changes in the ground reaction force–time curve, despite the fact that jump performance (height) was impaired for all of their post-warm-up jumps. The same group also suggested that a gluteal activation protocol can improve acceleration performance[13] but again this was based on a small, significant effect size (a difference in 10 m sprint time of 0.02 s; d=0.2, p=0.021). What is particularly surprising in all of this previous literature is the focus on investigating whether the performance outcome is improved, especially when the clinical rationale for including gluteal activation exercises in an athlete's programme is often more focused around improving movement quality.

Potentiation of the gluteal musculature by activation warm-up?

One of the most interesting findings of this study was the fact that there was a significant decrease in the EMG signal following the activation warm-up, despite the fact that the ground reaction forces were unchanged and that there was a trend for the estimated muscle forces to increase. There are two candidates that might explain this finding. The first is that after the gluteal activation warm-up the

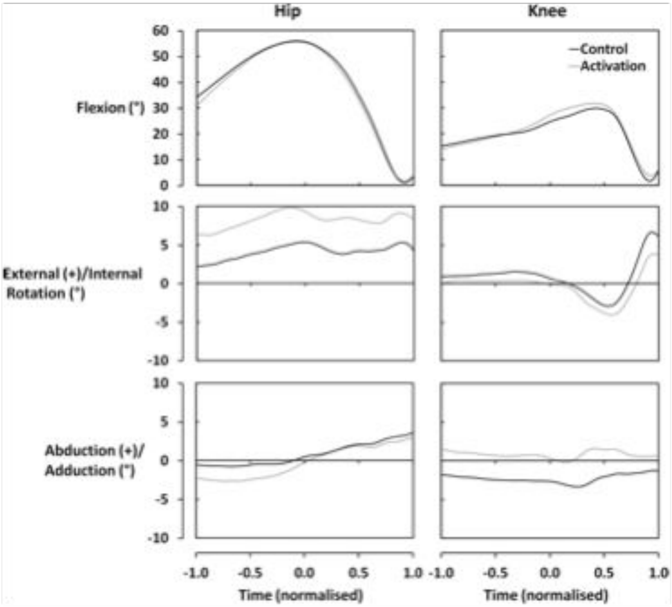

Figure 3 Hip and knee joint angles during the performance of a high hang pull after both a control and an activation warm-up.

kinematics of movement were altered in such a way that the glutes were able to operate at a more optimal position on their length–tension curve. This might then mean that a given level of neural drive would result in greater force production by the muscle. Certainly, our results did indicate that there may be some difference in the kinematics of the hip joint after the activation warm-up, but although the effect sizes of these differences were moderately large, they still only amounted to a few degrees, making this explanation seem less likely. The second possible explanation is that the gluteal activation

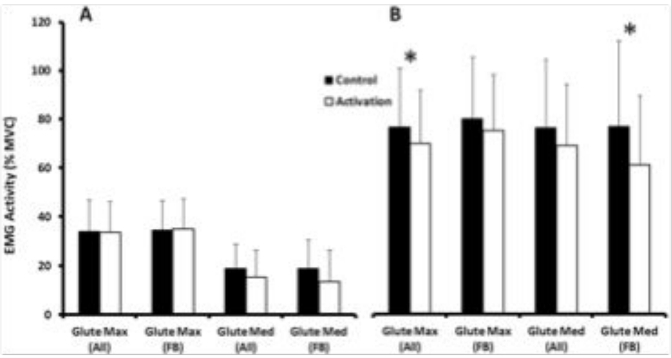

Figure 4 Mean peak electromyography (EMG) activity (% maximum voluntary contraction (MVC)) of gluteus maximus and medius while holding the barbell (A; baseline) and during the performance of a high hang pull (B) after both a control and an activation warm-up (* indicates a significant difference between control and activation trials; $p<0.05$).

warm-up potentiated the musculature of the glutes in such a way that the muscle contracted more strongly in response to a given neural signal. There is recent evidence[32] that specific training of the gluteal musculature can increase corticomotor excitability which is thought to be consistent with an improved ability of the neuromuscular system to recruit the affected musculature. That is, a stronger response is evoked by a given neural signal.[32] Our results are therefore consistent with the suggestion that the gluteal activation warm-up increased the corticomotor excitability of the glutes acutely. Such a phenomenon would offer an exciting validation of the use of therapeutic exercises to prime performance.

Of course, it should also be acknowledged that these suggestions are based on an entirely credulous interpretation of our findings and that both the muscle force estimates and the EMG data should be treated with caution. A further explanation for the discrepancy between EMG measurements and muscle force estimates might simply be that the muscle force estimates are incorrect. However, this alternative explanation still would not explain why the ground reaction forces remained unchanged when the EMG activity was decreased.

Musculoskeletal models can provide clinical insight of relevance to practitioners

In this study, the use of FreeBody was a key aspect of the experimental approach. Musculoskeletal modellers envisage that such models can be used to evaluate and simulate movement to provide general advice for clinicians, but that ultimately such models will progress to a point where they can be used on a subject-specific basis to guide medical, surgical, therapeutic and exercise interventions.[33 34] This study represents an important milestone towards this goal as, to our knowledge, this is the first study to employ a musculoskeletal model to evaluate the acute effect of an exercise intervention. The results of this study exemplify how musculoskeletal models can provide insight that may not be available from more traditional approaches. In particular, in this study, the EMG results alone might indicate that the gluteal activation warm-up actually caused a decrease in the involvement of the glutes in the movement, when the model analysis suggests the contrary.

Of course, the results of musculoskeletal modelling studies like this one are not without their own caveats. In particular, it is important that readers understand that the muscle forces reported here are estimates and are not directly measured. Similarly, the model employed here is generic and including further subject specific detail is likely to improve the accuracy of the muscle force estimation.[23 35]

Conclusions

The results of this study provide support for the employment of gluteal activation exercises as a strategy to acutely facilitate the recruitment of the gluteal and hamstring musculature and that this may result in improved movement quality. In addition, the results of this study add tacit support to the notion that the mechanism of the increased recruitment is through a potentiation of the neuromuscular system such that a given neural drive evokes greater force production.

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Contributors MP and DJC conceived the study. MP collected the data used in the study. All authors were involved in the study design, analysis and interpretation of the data, and preparation of the manuscript. All authors approved the final version and agreed to be accountable for the work.

Competing interests None declared.

Ethics approval St Mary's University Ethical Review Board.

Provenance and peer review Not commissioned; internally peer reviewed.

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IJSPT

ORIGINAL RESEARCH

ELECTROMYOGRAPHIC ANALYSIS OF GLUTEUS MEDIUS AND GLUTEUS MAXIMUS DURING REHABILITATION EXERCISES

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ABSTRACT

Purpose/Background: Previous research studies by Bolga, Ayotte, and Distefano have examined the level of muscle recruitment of the gluteal muscles for various clinical exercises; however, there has been no cross comparison among the top exercises from each study. The purpose of this study is to compare top exercises from these studies as well as several other commonly performed clinical exercises to determine which exercises recruit the gluteal muscles, specifically the gluteus medius and maximus, most effectively.

Methods: Twenty-six healthy subjects participated in this study. Surface EMG electrodes were placed on gluteus medius and maximus to measure muscle activity during 18 exercises. Maximal voluntary muscle contraction (MVIC) was established for each muscle group in order to express each exercise as a percentage of MVIC and allow standardized comparison across subjects. EMG data were analyzed using a root-mean-square algorithm and smoothed with a 50 millisecond time reference. Rank ordering of the exercises was performed utilizing the average percent MVIC peak activity for each exercise.

Results: Twenty-four subjects satisfied all eligibility criteria and consented to participate in the research study. Five of the exercises produced greater than 70%MVIC of the gluteus medius muscle. In rank order from highest EMG value to lowest, these exercises were: side plank abduction with dominant leg on bottom (103%MVIC), side plank abduction with dominant leg on top (89%MVIC), single limb squat (82%MVIC), clamshell (hip clam) progression 4 (77%MVIC), and font plank with hip extension (75%MVIC). Five of the exercises recruited gluteus maximus with values greater than 70%MVIC. In rank order from highest EMG value to lowest, these exercises were: front plank with hip extension (106%MVIC), gluteal squeeze (81%MVIC), side plank abduction with dominant leg on top (73%MVIC), side plank abduction with dominant leg on bottom (71%MVIC), and single limb squat (71%MVIC). Four of the exercises produced greater than 70%MVIC for both gluteus maximus and medius muscles.

Conclusions: Higher %MVIC values achieved during performance of exercises correlate to muscle hypertrophy.[20,22] By knowing the %MVIC of the gluteal musculature that occurs during various exercises, potential for strengthening of the gluteal muscles can be inferred. Additionally, exercises may be rank ordered to appropriately challenge the gluteal musculature during rehabilitation.

Keywords: gluteus medius, gluteus maximus, muscle recruitment, rehabilitation exercise

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This study was approved by the Institutional Review Board at Belmont University and informed consent was obtained from all subjects. This project was completed for partial fulfillment of a degree.

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INTRODUCTION

The lower extremity functions in a kinematic chain, leading many researchers in recent years to examine the mechanical effect of weak proximal musculature on more distal segments.[1,2] Previous research by Distefano,[3] Bolgla,[4] and Ayotte[5] has sought to determine the most appropriate exercises to strengthen the gluteal muscles due to their role in maintaining a level pelvis and preventing hip adduction and internal rotation during single limb support.[1,6] Measurement of such femoral torsion and pelvic rotation in the transverse plane, along with measurement of pelvic tilt in the sagittal plane can indicate abnormal alignment of the hip joint.[7] Numerous pathologies have been described which are related to the inability to maintain proper alignment of the pelvis and the femur, including: tibial stress fracture,[8] low back pain,[9,10] iliotibial band friction syndrome,[1,11] anterior cruciate ligament injury,[1,12] and patellofemoral pathology.[2,13,14,15,16,17] While Distefano,[3] Bolgla,[4] and Ayotte[5] have examined a wide range of exercises used to strengthen the hip musculature, to the knowledge of the authors, no cross comparison amongst the top exercises from each study has been performed.

Similar to Distefano,[3] Ayotte,[4] and Bolgla,[5] exercises examined in the current study were rank ordered according to their recruitment of specific gluteal musculature and expressed as a percent of the subject's maximum volitional isometric contraction (MVIC). By knowing the approximate percentage of MVIC (%MVIC) recruitment of each of the gluteal muscles in a wide variety of exercises, the exercises may be ranked to appropriately challenge the gluteal musculature. MVIC was established in the standard manual muscle testing positions for gluteus medius and maximus, as described by Daniels and Worthingham.[18] The use of the sidelying abduction position is supported by the results of Widler,[19] where similarity in EMG activity for weight bearing and sidelying abduction (ICC's 0.880 and 0.902 for the respective positions) demonstrated that it is acceptable to use the MVIC value obtained during the standard manual muscle test position in order to establish a percentage MVIC for a weight bearing exercise.

Several previously published research articles helped to establish the parameters for determining a sufficient level of muscle activation for strength gains referenced in the current study. Anderson found that in order for strengthening adaptation to occur, muscle stimuli of at least 40-60% of a subject's MVIC must occur.[20] When quantifying muscular strength, work by Visser correlates the use of a MVIC and a one-repetition maximum.[21] In order to gain maximal muscular hypertrophy, Fry's work suggests an 80-95% of a subject's one repetition maximum must be achieved.[22] Based on the work by Anderson,[20] Visser,[21] and Fry,[22] for the purposes of this study, exercises producing greater than 70%MVIC were deemed acceptable for enhancement of strength.

Distefano examined electromyography (EMG) signal amplitude normalized values of gluteus medius and gluteus maximus muscles during exercises of varying difficulty in order to determine which exercises most effectively recruit these muscles.[3] Rank order of exercises and %MVIC of Distefano's study can be viewed in Table 1. Of the top five exercises for the gluteus medius described by Distefano, the authors of the current study chose to reexamine sidelying hip abduction, single limb squat, and the single limb deadlift. Lateral band walk was not included in the current study as the researchers wished to only examine exercises that required no external resistance.

Research by Bolgla and Uhl also examined the magnitude of hip abductor muscle activation during rehabilitative exercises.[4] Their results may be viewed in Table 2. Of the exercises studied by Bolgla et al, the authors of the current study chose only to look at the pelvic drop and sidelying hip abduction. These two exercises were chosen since the primary intention of the current study was to compare an exercise's recruitment of the gluteal musculature, and not the activation effects of weight bearing versus non-weight bearing on the musculature.

Finally, Ayotte et al. used EMG to analyze lower extremity muscle activation of the pelvic stabilizers as well as the quadriceps complex during five unilateral weight bearing exercises,[5] displayed in Table 3. The authors of the current study elected to forgo analyzing a single-limb wall squat and a single-limb minisquat due to their similarity to the single-limb squat. Forward step-up and lateral step-up were included in the current analysis. The current study serves to compare top exercises from these previously published studies, as well as several other commonly performed

Table 1. *Findings of Distefano et al.[3] Values are described as %MVIC, followed by rank in parentheses.*

Exercise Condition	Glut Max %MVIC (rank)	Glut Med %MVIC (rank)
Side-lying hip abd	39 (6)	81 (1)
Clam with 30 hip flex	34 (10)	40 (10)
Clam with 60 hip flex	39 (6)	38 (12)
Single-limb squat	59 (1)	64 (2)
Single-limb deadlift	59 (1)	58 (4)
Lateral band walk	27 (12)	61 (3)
Forward lunge	44 (4)	42 (9)
Sideways lunge	41 (5)	39 (11)
Transverse lunge	49 (3)	48 (6)
Forward hop	35 (8)	45 (8)
Sideways hop	30 (11)	57 (5)
Transverse hop	35 (8)	48 (6)

Table 2. *Findings by Bolgla and Uhl,[4] represented as %MVIC.*

Exercise condition	Glut Med % MVIC
Pelvic drop	57
WB with flexion left hip abd	46
WB left hip abd	42
NWB sidelying hip abd	42
NWB standing hip abd	33
NWB standing flexed hip abd	28

* WB = Weight Bearing, NWB = Non-Weight Bearing, Abd = Abduction

clinical exercises in order to determine the exercises that are most effective at recruiting the gluteus maximus and medius.

METHODS

Subjects

This study was approved by the Institutional Review Board of Belmont University. A total of 26 subjects were recruited from within the university and surrounding community through flyers and word of mouth. Healthy subjects who were able to perform exercise for approximately one hour were included in the study and reported to the laboratory for a single testing session. At this time they completed an informed consent form as well as a health history form and comprehensive lower quarter screen to identify exclusionary criteria. Pain when performing exercises, current symptoms of injury, history of ACL injury or any lower extremity surgery within past two years, and age of less than 21 years were criteriariteria for exclusion.

Table 3. *Findings of Ayotte et al.[5] Values are described as %MVIC, followed by rank in parentheses.*

Exercise condition	Glut Max %MVIC (rank)	Glut Med % MVIC (rank)
Wall squat	86 (1)	52 (1)
Mini-squat	57 (4)	36 (5)
Front step up	74 (2)	44 (2)
Lateral step up	56 (5)	38 (3)
Retro step up	59 (3)	37 (4)

Testing Procedures

EMG data were collected and analyzed on the dominant leg, identified by which leg the subject used to kick a ball.[3,5,23] Alcohol wipes were used to clean the skin over the gluteal region prior to electrode placement. Schiller Blue Surface electrodes (Schiller America Inc.; Doral, FL) were placed over the gluteus medius and gluteus maximus muscles of the subject's dominant

Figure 1. *Maximum voluntary isometric contraction testing example set up.*

side,[4] per standard EMG protocol.[24] In order to ensure consistent electrode placement throughout testing, electrodes were secured with surgical tape. Placement was confirmed by viewing EMG signals while separately activating each muscle. Subjects then performed a sub-maximal warm-up for five minutes on a stationary bicycle while watching a brief video of the exercises to be performed in order to familiarize subjects with exercise technique. A five-second MVIC was performed three times in the standard manual muscle testing protocol positions for each gluteal muscle[18,19] with one minute of rest between each contraction. A strap was secured around the distal femur during muscle testing for both muscles to ensure standardization of resistance (Figure 1). Verbal encouragement was given with each trial.

Exercise order was randomized using a random pattern generator[25] in order to avoid any order bias due to fatigue. Subjects were barefoot while performing exercises to prevent any potential variations that may have occurred due to footwear. Two minutes of rest was given between the performance of each exercise. Subjects performed eight repetitions of each exercise, three practice repetitions and five repetitions that were used for data collection. Exercises were performed to a metronome set at 60 beats per minute to standardize the rate of movement across subjects.

To replicate a clinical setting, researchers chose to use visual analysis of movement to ensure proper exercise technique rather than an electrogoniometer or movement analysis software since both of these

Figure 2. *CorTex™ equipment (Performance Dynamics, San Diego, CA).*

procedures are unlikely to be available in a clinic. To ensure proper exercise technique, each subject was allowed three practice repetitions prior to data collection and any necessary verbal and tactile cues by the instructing researcher. A description of each exercise may be found in Appendix A. After completing all exercises, the subject's MVIC was reassessed to ensure electrodes had not been displaced during testing.

The equipment used for the conditions which required an unstable surface is the Core-Tex Balance Trainer™ (Performance Dynamics; San Diego, CA), a new piece of exercise equipment which is a platform mounted on a half-sphere atop a circular basin lined with ball bearings, creating an unstable and rapidly accelerating surface (Figure 2). The Core-Tex™ was developed to train a healthy fitness population; however, it may also be used to train individuals during rehabilitation in a clinical setting.

Data Analysis

All data were rectified and smoothed using a root-mean-square algorithm, and smoothed with a 50 millisecond (msec) time reference. Peak amplitudes were averaged over a 100 msec window of time, 50 msec prior to peak and 50 msec after the peak.

Table 4. *Results for Gluteus Medius recruitment, %MVIC and rank for all exercises.*

Exercise condition	# Subjects Included for analysis	%MVIC Gluteus Medius	Rank Gluteus Medius
Side plank abd, DL down	21	103.11	1
Side plank abd, DL up	22	88.82	2
Single limb squat	22	82.26	3
Clamshell (Hip Clam) 4	23	76.88	4
Front plank with Hip Ext	23	75.13	5
Clamshell (Hip Clam) 3	22	67.63	6
Side-lying abd	23	62.91	7
Clamshell (Hip Clam) 2	22	62.45	8
Lateral step-up	21	59.87	9
Skater squat	22	59.84	10
Pelvic Drop	23	58.43	11
Hip circumduction, stable	23	57.39	12
Dynamic Leg Swing	22	57.30	13
Single limb deadlift	22	56.08	14
Single limb bridge, stable	22	54.99	15
Forward step-up	22	54.62	16
Single limb bridge, unstable	20	47.29	17
Clamshell (Hip Clam) 1	22	47.23	18
Quadruped hip ext, DOM	23	46.67	19
Gluteal squeeze	23	43.72	20
Hip circumduction, unstable	23	37.88	21
Quadruped hip ext, non-DOM	23	22.03	22

To determine MVIC, the middle 3/5ths time for each manual muscle test trial was isolated and the peak value determined. The highest peak value out of the three trials was recorded and determined to be the MVIC.

In order to establish %MVIC for each exercise performed by an individual subject, data were collected for the last five repetitions of each exercise. If the EMG data were clearly cyclic, the middle three repetitions were analyzed. If it was difficult to determine when a repetition started and stopped on visual analysis of EMG data, then the middle 3/5ths of the total time to perform the five repetitions was analyzed. The highest peak out of the three repetitions was then divided by MVIC to yield %MVIC for that individual.

To determine %MVIC values for rank ordering of exercises, the %MVIC for each muscle was averaged between all subjects for each exercise.

RESULTS

Twenty-four subjects satisfied all eligibility criteria and consented to participate in the research study. Data from one subject were excluded due to faulty data from the EMG leads for both muscles, and data from another subject were excluded due to faulty data from the EMG lead for gluteus maximus only. There were a few other isolated instances of faulty data from EMG leads, in which case the subject's data were excluded from analysis for that specific exercise. The number of subjects included in data analysis for each exercise can be referenced in Tables 4 and 5. Due to the advanced level of some of the exercises included in the current study, such as single limb bridge on unstable surface and side plank, some subjects were unable to successfully complete all exercises. In these instances, subject data were not included in data analysis for that specific exercise. Peak amplitudes,

Table 5. *Results for Gluteus Maximus recruitment, %MVIC and rank for all exercises.*

Exercise condition	# Subjects Included for analysis	%MVIC Gluteus Maximus	Rank Gluteus Maximus
Front plank with Hip Ext	22	106.22	1
Gluteal squeeze	22	80.72	2
Side plank abd, DL up	22	72.87	3
Side plank abd, DL down	21	70.96	4
Single limb squat	22	70.74	5
Skater squat	21	66.18	6
Lateral step-up	20	63.83	7
Quadruped hip ext, DOM	22	59.70	8
Single limb deadlift	21	58.84	9
Forward step-up	22	54.67	10
Single limb bridge, stable	21	54.24	11
Clamshell (Hip Clam) 1	22	53.10	12
Side-lying abd	22	51.13	13
Single limb bridge, unstable	18	49.35	14
Hip circumduction, stable	22	37.85	15
Dynamic leg swing	22	33.65	16
Hip circumduction, unstable	22	28.87	17
Clamshell (Hip Clam) 3	22	26.63	18
Clamshell (Hip Clam) 4	22	26.22	19
Pelvic Drop	22	25.10	20
Quadruped hip ext, non-DOM	22	21.04	21
Clamshell (Hip Clam) 2	22	12.36	22

Table 6. *Top exercises for muscle activation of both gluteus medius and gluteus maximus (>70% MVIC).*

Exercise condition	%MVIC Gluteus Medius	%MVIC Gluteus Maximus
Front plank with Hip Ext	75.13	106.22
Side plank abd, DL up	88.82	72.87
Side plank abd, DL down	103.11	70.96
Single limb squat	82.26	70.74

expressed as %MVIC for gluteus medius and gluteus maximus, are rank ordered in Tables 4 and 5. Five of the exercises produced greater than 70%MVIC of the gluteus medius muscle. In rank order from highest EMG value to lowest, these exercises were: side plank abduction with dominant leg on bottom (103%MVIC), side plank abduction with dominant leg on top (89%MVIC), single limb squat (82%MVIC), clamshell (hip clam) progression 4 (77%MVIC), and font plank with hip extension (75%MVIC). Five of the exercises recruited gluteus maximus with values greater than 70%MVIC. In rank order from highest EMG value to lowest, these exercises were: front plank with hip extension (106%MVIC), gluteal squeeze (81%MVIC), side plank abduction with dominant leg on top (73%MVIC), side plank abduction with dominant leg on bottom (71%MVIC), and single limb squat (71%MVIC). Table 6 displays the exercises that produced greater than 70%MVIC for both gluteus medius and maximus muscles. These exercises included front plank with hip extension (75%MVIC, 106%MVIC), side plank abduction with dominant leg on top (89%MVIC, 73%MVIC), side plank abduction with dominant leg on bottom (103%MVIC, 71%MVIC), and single limb squat (82%MVIC, 71%MVIC) for gluteus medius and maximus respectively.

DISCUSSION

The main objective of this study was to examine muscle activity during common clinical exercises used to strengthen the gluteus medius and gluteus maximus muscles. This study sought to analyze and compare information reported in previous studies by Distefano, Bolga, and Ayotte regarding ranking of various therapeutic exercises using %MVIC. The secondary objective was to describe %MVIC for other commonly used therapeutic exercises not previously reported upon. The authors of this study chose to examine peak amplitude averaged over a 100 ms window, 50 ms prior to peak and 50 ms after the peak, during repetitions five, six and seven, the highest of which was converted to %MVIC. This methodology is similar to studies by both Distefano[3] and Bolgla.[4] Ayotte et al. averaged EMG activity over a 1.5 sec window during the concentric phase of each exercise.[5] Due to slight differences in data collection and data analysis between the current study, and studies conducted by Distefano, Bolgla and Ayotte, interpretation of results and similarities across studies will predominantly address the sequence of rank order as opposed to absolute values for the %MVIC.[3,4,5]

There were two exercises where %MVIC was found to be higher than MVIC, side plank abduction with dominant leg down (103%MVIC) for gluteus medius and front plank with hip extension (106%MVIC) for gluteus maximus. There are several possibilities as to why these findings may have occurred. One possibility is that subjects lacked sufficient motivation to perform a true maximal contraction during MVIC testing, despite the fact that verbal encouragement was given to all subjects during max testing of both muscles. Another possibility is that subjects were not able to truly give a maximum effort during the manual muscle test. Authors of previous research have reported that in order to obtain a true maximum contraction, it is necessary to superimpose an interpolated twitch, which is an electrically stimulated contraction, on top of the maximum voluntary contraction.[26] Current research in electrophysiology is further examining this phenomenon with mixed results regarding sensitivity of various interpolated twitch techniques, differences in methodology, and interpretation of their results.[27,28,29] Future researchers using MVIC for standardization across subjects should follow this research closely in order to ensure the most accurate methodology is used for establishing maximal voluntary muscle contractions. A final possibility is that with these exercises there was substantial co-contraction of the core musculature, which may have led to higher values than could be obtained during isolated volitional contraction. In the MMT positions used to establish MVIC the pelvis is stabilized against the surface of the table with relatively isolated muscle recruitment. In both of the above mentioned exercises, the pelvis does not have external support and higher EMG values could reflect increased activity due to an increased need for stabilization resulting in synergistic co-contraction. Future research may need to examine differences in muscle recruitment and activation patterns in exercises that test isolated muscle function versus ones that require core stabilization resulting in co-contraction.

Gluteus Medius

Table 7 depicts the top gluteus medius exercises determined by the authors of the current study as referenced to the exercises examined in studies performed by Distefano,[3] Bolgla,[4] and Ayotte.[5] The authors of the current study found highest %MVIC peak values for side plank abduction with dominant leg on bottom (103%MVIC), side plank abduction with dominant leg on top (89%MVIC), single limb squat (82%MVIC), clamshell progression 4 (77%MVIC), and front plank (75%MVIC) as outlined in Table 7. Four of the top five exercises were not previously examined by Distefano,[3] Bolga,[4] or Ayotte.[5] All of these exercises exhibited greater than 70%MVIC, the peak amplitude necessary for enhancement of strength, suggesting they may have benefits for gluteus medius strengthening. However, these exercises are all very challenging and would not be appropriate for initial strengthening in patients with weak core musculature due to their high degree of difficulty and the amount of core stabilization required. The possible exception may be clamshell progression 4, due to the stabilization provided to the subject when lying on the floor to perform the

Table 7. *Comparison of rank order of exercises for recruitment of gluteus medius between the current study and Distefano,[3] Bolgla,[4] and Ayotte,[5] using %MVIC*

	Exercise condition	Current Study	Distefano[3]	Bolgla[4]	Ayotte[5]
1	Side plank abd, DL down	103			
2	Side plank abd, DL up	89			
3	Single Limb Squat	82	64		52*
4	Clamshell (Hip Clam) 4	77			
5	Front plank with Hip Ext	75			
7	Side-lying abd	63	81	42	
9	Lateral step-up	60			38
11	Pelvic Drop	58		57	
14	Single limb deadlift	56	58		
16	Forward step-up	55			44
18	Clamshell (Hip Clam) 1	47	40		

*Single-limb wall squat

exercise. While the top exercises in this study produced the greatest peak amplitude EMG values, it is also important to consider functional demands and dosage when selecting an exercise for muscle training and strengthening, especially in early stages of rehabilitation of a weak or under-recruited muscle.

The top gluteus medius exercises from Distefano's study were sidelying hip abduction (81%MVIC), single-limb squat (64%MVIC), and single limb dead lift (58%MVIC).[3] With the exception of single limb squat, the current study found similar rank order with values of 63%MVIC, 82%MVIC, and 56%MVIC respectively. Of note, Distefano's subjects performed the single limb squat to a predetermined knee flexion angle of approximately 30 degrees,[3] while the current study had the subjects perform the exercise to a predetermined chair height of 47 cm. This difference in methodology may account for the difference in findings across the two studies. The methodology used by Distefano may allow for greater normalization, as squatting to a predetermined knee flexion angle allows for equal challenge to all subjects, where as squatting to a predetermined height creates a greater challenge for taller subjects.

Bolga's top exercise for gluteus medius was the pelvic drop (57%MVIC).[4] The current study found a similar value at 58%MVIC, although this exercise was ranked 11th out of the 22 exercises evaluated. This exercise should not be discounted; however, as it is a functional training exercise for pelvic stabilization in single limb stance, and many gait abnormalities and lower extremity pathologies are the result of the gluteus medius muscle's inability to properly and effectively stabilize the pelvis during single limb stance.

Bolga found sidelying abduction to have a value of 42%MVIC,[4] which is significantly lower than the findings in either the Distefano[3] or the current study. In general, qualitative movement analysis during performance of sidelying abduction reveals poor technique with frequent substitution using the tensor fascia lata muscle demonstrated through increased hip flexion during abduction, which may have accounted for the low value found in the Bolga study.[6] Furthermore, subjects in both the Distefano and the Bolgla study maintained the bottom leg in neutral hip extension and knee extension,[3,4] while subjects in the current study were allowed to flex the bottom hip and knee in order to provide greater support and stabilization during abduction of the top leg.

Ayotte's top exercise was the unilateral wall squat (52%MVIC),[5] which is comparable to the single limb squat, ranking in the top three exercises in both the current study and in Distefano's study,[3] although the external stabilization provided in the unilateral wall squat should be considered. Ayotte ranked forward step-up (44%MVIC) higher than lateral step-up (38%MVIC),[5] whereas the authors of the current study ranked lateral step-up (60%MVIC) higher than forward step-up (55%MVIC). It should be noted that subjects were allowed upper extremity external support during the exercise in Ayotte's study which may

Table 8. *Comparison of rank order of exercises for recruitment of gluteus maximus between the current study and Distefano,[3] and Ayotte,[5] using %MVIC.*

	Exercise condition	Current Study	Distefano[3]	Ayotte[5]
1	Front plank with Hip Ext	106		
2	Gluteal squeeze	81		
3	Side plank abd, DL up	73		
4	Side plank abd, DL down	71		
5	Single limb squat	71	59	86*
7	Lateral step-up	64		56
9	Single limb deadlift	59	59	
10	Forward step-up	55		74
12	Clamshell (Hip Clam) 1	53	34	
13	Side-lying abd	51	39	

*Single-limb squat

account for these differences,[5] along with differences in data analysis described previously.

Gluteus Maximus

Table 8 depicts the top exercises for gluteus maximus of the current study. These include front plank with hip extension (106%MVIC), gluteal squeeze (81%MVIC), side plank abduction with dominant leg on top (73%MVIC), side plank abduction with dominant leg on bottom (71%MVIC), and single limb squat (71%MVIC). The top four exercises from the current study were not performed in other studies. Bolgla's study did not include assessment of performance of the gluteus maximus so will not be included in the discussion below.[4]

Distefano's top exercises were single limb squat (59%MVIC), single limb dead lift (59%MVIC), and sidelying hip abduction (39%MVIC).[3] Subjects performing these same exercises in the current study produced results of 71%MVIC, 59%MVIC, and 51%MVIC, respectively, demonstrating the same rank order of muscle activity as these exercises in the Distefano study.[3] The only differences in rank ordering between the current study and Distefano's for gluteus maximus were between clamshell progression 1 and sidelying abduction;[3] however, within each study there was less than 5%MVIC difference for each exercise when determining rank order (Table 8). As previously noted, differences in technique and substitution are common occurrences during the performance of sidelying abduction which may account for the differences found between the two studies.

Ayotte ranked forward step-up (74%MVIC) higher than lateral step-up (56%MVIC),[5] whereas the current study ranked lateral step-up (64%MVIC) higher than forward step-up (55%MVIC). Again, differences could be attributed to variances in technique or the ability of subjects in Ayotte's study to use external upper extremity support[5] as well as differences in data analysis.

The low ranking for stable single limb bridge (11th) and unstable single limb bridge (14th) was somewhat surprising as both are common exercises used clinically for gluteus maximus strengthening. There were several instances of subjects reporting hamstring cramping during bridging on the unstable surface, which led the researchers to suspect substitution with the hamstrings during this exercise. The same may hold true for bridging on the stable surface, however there were fewer complaints. Future studies should examine muscle recruitment and activation patterns of gluteus maximus and the hamstrings during various bridging activities.

The effect of a subject's attention to volitional contraction of a muscle during an exercise should also be considered. The gluteal squeeze was the only exercise where verbal cues were explicitly given to maximally contract the gluteal muscles while performing the exercise, which could possibly have contributed to its high ranking for performance by the gluteus maximus. Future research should examine the difference in amount, if any, noted in muscle recruitment when verbal instructions are given to concentrate on the muscle contraction while performing the exercise versus no verbal instructions during performance. The effects of tone of voice, volume of cues, and frequency of verbal cueing are unknown.

CONCLUSION

Anderson and Fry have previously reported that higher %MVIC values with exercises correlate to muscle hypertrophy.[20,22] By knowing the %MVIC of the gluteus maximus and medius that occurs during various exercises, the potential for strengthening these muscles can be inferred. Subsequently, exercises may be ranked to appropriately challenge the gluteus maximus and medius during rehabilitation. The authors of the current study found patterns within their results consistent with previous research published by Distefano and Bolgla.[3,4] The authors conclude that differences in data collection and analysis as well as the use of external upper extremity support may have accounted for the differences noted between the current study and the study by Ayotte.[5] One of the purposes of the current study was to provide a rank ordered list of exercises for the recruitment of the gluteus maximus and medius. These rank ordered lists may help form the basis for a graded rehabilitation program. For patients early in the rehabilitation process, the clinician should systematically determine which muscle they are wishing to strengthen and use less difficult (lower %MVIC) exercises. In order to maximally challenge a patient's gluteus maximus and medius, the authors recommend using a front plank with hip extension, a single limb squat, and a side plank on either extremity with hip abduction.

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APPENDIX A

1. Clamshell (hip clam) Progression: Each exercise is performed with the subject sidelying on the non-dominant side. (Figure 3)

a. Progression 1 (upper left): Start position is sidelying with hips flexed to approximately 45 degrees, knees flexed, and feet together. Subject externally rotates the top hip to bring the knees apart for one metronome beat and returns to start position during the next beat.

b. Progression 2 (upper right): Start position identical to progression 1; however, in this progression subject keeps the knees together while internally rotating the top hip to lift the top foot away from the bottom foot for one metronome beat, returning to the start position during the next beat

c. Progression 3 (lower left): The subject is positioned identical to progressions 1 and 2, but with the top leg raised parallel to the ground. The subject maintains the height of the knee while internally rotating at the hip by bringing the foot toward the ceiling for one beat and then returns to the start position during the next beat.

d. Progression 4 (lower right): The subject is positioned the same as progression 3, but with the hip fully extended. As in progression 3, the subject maintains the height of the knee and internally rotates at the hip by bringing the foot toward the ceiling for one beat and returns to the start position with knee and ankle in line during the next beat.

2. Pelvic drop: Subject stands with dominant leg on the edge of a 5 cm box (right), and then lowers the heel of the non-dominant leg to touch the ground without bearing weight, for one beat (left). Subject returns foot to the height of the box while keeping the hips and knees extended for one beat. (Figure 4)

Figure 3.

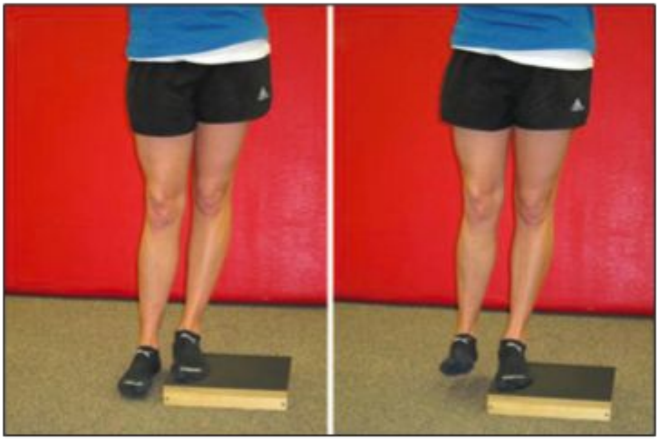

Figure 4.

Figure 5.

3. Sidelying abduction: Start with subject sidelying on non-dominant side. Subject flexes the hip and knee of the support side and then abducts the dominant leg to approximately 30 degrees while maintaining neutral or slight hip extension and knee extension with the toes pointed forward for a count of two beats up and two beats down. (Figure 5)

4. Side Plank with Abduction, dominant leg up: (Start with subject in a side plank position with dominant leg up. Subject is instructed to keep shoulders, hips, knees, and ankles in line bilaterally, and then to rise to plank position with hips lifted off ground to achieve neutral alignment of trunk, hips, and knees. The subject is allowed upper extremity support as seen

Figure 6.

Figure 7.

on left. While balancing on elbows and feet, the subject raises the top leg into abduction (right) for one beat and then lowers leg for one beat. Subject maintains plank position throughout all repetitions (Figure 6).

5. Side Plank with Abduction, dominant leg down: Exercise position is identical to Exercise 4 except on the opposite side. Subject is instructed to abduct the non-dominant uppermost leg for two beats and lowers leg for two beats. Subject maintains plank position throughout all repetitions.

6. Front Plank with Hip Extension: Start with subject prone on elbows in plank with trunk, hips, and knees in neutral alignment (left). Subject lifts the dominant leg off of the ground, flexes the knee of the dominant leg, and extends the hip past neutral hip alignment by bringing the heel toward the ceiling (right) for one beat and then returns to parallel for one beat. (Figure 7)

7. Single Limb Bridging on Stable Surface: Start with subject in hook-lying position (left). The subject is instructed to bridge on both legs by keeping the feet on the floor and raising hips off the ground to achieve neutral trunk, hip, and knee alignment for one beat. From this position, the subject extends the knee of the non-dominant leg to full knee extension while keeping the femurs parallel (right) for one beat, returns the non-dominant leg to the bridge position for one beat, and then lowers the body back to the ground for one beat (Figure 8).

8. Single Limb Bridge on Unstable Surface: Subject is positioned as in Exercise 7 and places the dominant foot in the center of the Core-Tex™ (left).

Figure 8.

Figure 9.

The subject performs the same sequence as above (right) while maintaining the disc of the Core-Tex™ in the center. (Figure 9)

9. Hip Circumduction on Stable Surface: The subject places the non-dominant leg on the outside of the base of the Core-Tex™ and stands to the side of the Core-Tex™ on the dominant leg (left). The subject performs a single limb squat while tracing the toe of the non-dominant leg on the outside of the Core-Tex™ base (right) in an arc for three beats, then traces the toe back to the start, while returning to a standing position for three beats. Subjects were allowed two-finger unilateral upper extremity support on the frame of the Core-Tex™ for balance assist. (Figure 10).

10. Hip Circumduction on Unstable Surface: In standing, the subject places the non-dominant foot on the outer edge of the Core-Tex™ and stands to the side of the Core-Tex™ on the dominant leg (left). The subject then performs a single limb squat on the dominant leg while drawing an arc with the non-dominant foot, extending the arc away from the subject for three beats (right). The subject then returns the foot to the

Figure 10.

Figure 11.

starting position by drawing the foot in, while returning to a standing position for three beats. Subjects were allowed upper extremity support as in Exercise 9. (Figure 11)

11. Single Limb Squat: Subject stands on the dominant leg, slowly lowering the buttocks to touch a chair 47cm in height for two beats and then extends back to standing for two beats. (Figure 12)

Figure 12.

Figure 13.

Figure 14.

Figure 15.

12. Single Limb Deadlift: Subject stands on the dominant leg and slowly flexes at the hip, keeping the back straight, to touch the floor with the opposite hand for two beats. Subject then extends at the hip to standing for two beats. Subjects were permitted to have knees either straight or slightly bent in the case that hamstring tightness limited subject's ability to touch the floor. (Figure 13)

13. Dynamic Leg Swing: Subject is positioned in standing on the dominant leg, and then begins to swing the non-dominant leg (with the knee flexed) into hip flexion (left) and extension (right) at a rate of one beat forward and one beat backward. Subjects were instructed to move through a smooth range of hip motion and to not allow their trunk to move out of the upright position. (Figure 14)

14. **Forward Step-up:** Beginning with both feet on the ground, subject steps forward onto a 20cm step with the dominant leg for one beat. Subject then steps up with the non-dominant leg during the next beat. Subject then lowers the non-dominant leg back to the ground for one beat followed by the dominant leg during the next beat. (Figure 15)

Figure 16.

15. Lateral Step-up: Subject stands on the edge of a 15cm box on the dominant leg and squats slowly to lower the heel of the non-dominant leg toward floor for one beat and then returns to start position during the next beat. (Figure 16)

16. Quadruped Hip Extension: In quadruped (left) the subject extends the dominant leg at the hip, while keeping the knee flexed 90 degrees, to lift the foot toward the ceiling (right) to achieve neutral hip extension for two beats and then returns the dominant leg to the start position for two beats. This exercise was repeated with the non-dominant leg and EMG values were recorded in order to measure activity as both the stabilizing and moving leg. (Figure 17)

17. Skater Squat: Subject stands on the dominant leg and performs a squat to a comfortable knee flexion angle for two beats down and two beats up with non-dominant leg extended at the hip and flexed at the knee. The torso twists during the squat. The toe of the non-dominant leg was permitted to touch the ground between repetitions. (Figure 18)

18. Gluteal Squeeze: In standing with feet shoulder-width apart, subject squeezes gluteal muscles for two beats and then relaxes for two beats. Subjects were instructed to maximally contract the gluteal musculature during the exercise.

Figure 18.

Figure 17.

IJSPT

SYSTEMATIC REVIEW

AN EXAMINATION OF THE GLUTEAL MUSCLE ACTIVITY ASSOCIATED WITH DYNAMIC HIP ABDUCTION AND HIP EXTERNAL ROTATION EXERCISE: A SYSTEMATIC REVIEW

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ABSTRACT

Background: A wide variety of hip abduction and hip external rotation exercises are used for training, both in athletic performance and in rehabilitation programming. Though several different exercises exist, a comprehensive understanding of which exercises best target the gluteus maximus (Gmax) and gluteus medius (Gmed) and the magnitude of muscular activation associated with each exercise is yet to be established.

Purpose: The purpose of this systematic review was to quantify the electromyographic (EMG) activity of exercises that utilize the Gmax and Gmed muscles during hip abduction and hip external rotation.

Methods: Pubmed, Sports Discuss, Web of Science and Science Direct were searched using the Boolean phrases (gluteus medius OR gluteus maximus) AND (activity OR activation) AND (electromyography OR EMG) AND (hip abduction OR hip external rotation). A systematic approach was used to evaluate 575 articles. Articles that examined injury-free participants of any age, gender or activity level were included. No restrictions were imposed on publication date or publication status. Articles were excluded when not available in English, where studies did not normalize EMG activity to maximum voluntary isometric contraction (MVIC), where no hip abduction or external rotation motion occurred or where the motion was performed with high acceleration.

Results: Twenty-three studies met the inclusion criteria and were retained for analysis. The highest Gmax activity was elicited during the lateral step up, cross over step up and rotational single leg squat (ranging from 79 to 113 % MVIC). Gmed activity was highest during the side bridge with hip abduction, standing hip abduction with elastic resistance at the ankle and side lying hip abduction (ranging from 81 to 103 % MVIC).

Limitations: The methodological approaches varied between studies, notably in the different positions used for obtaining MVIC, which could have dramatically impacted normalized levels of gluteal activation, while variation also occurred in exercise technique and/or equipment.

Conclusions: The findings from this review provide an indication for the amount of muscle activity generated by basic strengthening and rehabilitation exercises, which may assist practitioners in making decisions for Gmax and Gmed strengthening and injury rehabilitation programs.

Keywords: EMG, gluteal musculature, hip strength, rehabilitation

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INTRODUCTION

A wide variety of hip abduction and hip external rotation exercises are used for training, both in athletic performance and in rehabilitation programming. Though several different exercise protocols exist, scientific evaluation of their specific effects on the gluteus maximus (Gmax) and gluteus medius (Gmed) has yet to establish which exercises activate the musculature and what level of activation is elicited. The primary actions of the Gmax are hip extension and hip external rotation,[1-3] with the superior area of the Gmax also functioning as a hip abductor.[4,5] The Gmed functions as a hip abductor[2] and hip rotator[6] with the anterior area of the Gmed performing hip internal rotation while the posterior area performs hip external rotation.[2,7] The gluteal musculature may significantly participate in dual roles of enhancing athletic performance[3,8-10] while preventing and contributing to the rehabilitation of lower extremity injuries.[10-14] The Gmax and Gmed musculature extensively contribute to weight bearing movements by assisting in load transference through the hip joint,[15] supplying local structural stability to the hip joint and maintaining lower extremity alignment of the hip and knee joints.[16] Performance deficiency in these selected hip muscles results in altered pelvofemoral biomechanics which is linked to lower extremity pathology.[3,17-19] This is highlighted when the hip abductors and external rotators fail to produce sufficient torque during weight bearing movements resulting in excessive hip adduction and internal rotation, an increase in knee valgus angle and pelvic drop.[17-20]

Hip abductor weakness may lead individuals to adopt movement strategies to mask their weakness,[21] resulting in compensatory motions at the lower back, hip, and knee.[5,10,22] Consequently, individuals performing these movements are often observed doing both hip abduction and excessive lateral pelvic movement caused by increased activity of the quadratus lumborum.[23] Gluteal weakness and ensuing hip dysfunction has a strong relationship (r = −.74) with knee pathology[24] while a specific weakness in hip abduction and external rotation has been associated with patellofemoral pain syndrome.[3,25] Janda and Jull[26] and, Page, Frank and Lardner[27] have suggested that an association between gluteal musculature inhibition and low back pain exists. Moreover, a weakness in hip abductor musculature and thus subsequent strengthening exercises are prescribed for iliotibial band syndrome,[28,29] chronic ankle instability[30,31] and patellofemoral pain syndrome.[32, 33]

Examining hip abductor strength can be accomplished through various clinical tools and procedures and in both non-weight-bearing (NWB) body positions: side-lying or supine and in a weight-bearing (WB) body position: standing.[34] The side-lying position is frequently utilized to test hip abductor muscle strength in clinical settings[35] and is generally the suggested position by manufacturers of isokinetic testing devices.[34] The supine position neutralizes the effects of gravity and provides an option for individuals to avoid lying on an injured affected side[36] while the standing position is proposed by Cahalan, Johnson and Chao[37] to be the most functional position when assessing hip abductor strength as the majority of daily living activities involve hip abduction performed in this position. Wilder et al[34] noted that most variations between hip abductor strength exist due to the chosen testing position.

Electromyography (EMG) may be used to assess the activation of a muscle as measured by electrical activity levels, with the general consensus assumed that exercises producing higher levels of activation are generally accepted to be more appropriate to use for strengthening.[38] It has been proposed that the minimum effort to obtain a strengthening stimulus is approximately 40-60% of a maximum voluntary isometric contraction (MVIC)[38-42] with muscle activity of less than 25 % MVIC indicating that the muscle is functioning in an endurance capacity or to maintain stability.[38] To assist with classification of low to high muscle activity in this article, the authors of the current study have used a classification scheme of activity.[43-45] Activity from 0 % to 20 % MVIC is considered low level, 21 % to 40 % MVIC a moderate level, 41 % to 60 % MVIC a high level, while greater than 60 % MVIC a very high level. Analyzing exercises in such a manner may contribute to understanding neuromuscular control during activities and assist in assessing, selecting, and systematically progressing exercises.[46]

With this in mind the purpose and focus of this systematic review was to quantify the EMG activity associated with WB and NWB exercises that utilized hip abduction or external rotation. Exercises were grouped into levels of % MVIC as per the classification scheme[43-45] to assist practitioners in making decisions for Gmax and Gmed strengthening and rehabilitation. The authors hypothesized that exercises that are more demanding in movement i.e. dynamic exercise that requires a changes in angle from more than one joint and therefore requires greater joint stabilization, would result in greater levels of % MVIC.

METHODS

Literature Search Strategies

The review was conducted in accordance with PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-analyses) statement guidelines.[47] A systematic search of the research literature was undertaken for studies that investigated EMG activity (given as mean % MVIC) for either the Gmax or Gmed in resistance training exercises (bodyweight, band, cable, free-weight, machine) that utilized dynamic hip abduction or external rotation. Studies were found by searching Pubmed, Sports Discuss, Web of Science and Science Direct electronic databases from inception to March 2015. The following Boolean search phrases were used (gluteus medius OR gluteus maximus) AND (activity OR activation) AND (electromyography OR EMG) AND (hip abduction OR hip external rotation). Additional studies were also found by reviewing the reference lists from retrieved studies.

Inclusion and Exclusion Criteria

Articles that examined injury-free participants of any age, sex or activity level were included. No restrictions were imposed on publication date or publication status. Studies were limited to English language. Studies were excluded that examined isometric hip abduction or external rotation movements (e.g. standing wall-push exercise) as well as single leg hip extension movements (e.g. lunge and single leg bridge) as even though there is frontal/transverse plane stability and torque required, there is no hip abduction or external rotation motion required. Some exercises such as the lateral lunge, lateral step-up and cross over step-up were included since they involve hip abduction/external rotation motion and torque production, but movements like these do contain an unfair advantage since they also require hip extension torque and movement in the sagittal plane. Despite their combined action, authors made a judgment call to include them in the current analysis as these exercises are typically used in a physiotherapeutic setting for injury rehabilitation type activity. Plyometric or hopping movements were also excluded as they are performed with higher acceleration, thus they have an unfair advantage in terms of eliciting high levels of gluteal activation. Moreover, plyometric exercises are higher end performance type exercises and should be used once an individual exhibits prerequisite strength levels (eccentric) which includes activation, mobility and stability. Additionally studies were excluded that did not normalize EMG activity to MVIC.

Study Selection

A search of electronic databases and a scan of article reference lists revealed 575 relevant studies (Figure 1). After applying the inclusion and exclusion criteria 23 studies were retained for further analysis.

RESULTS

There were a total number of 467 subjects (194 male, 197 female, 76 sex not provided) while the total number of exercise variations were 52. See Appendix 1 for details on all included studies.

Exercise Position

The studies considered in this systematic review were conducted in either a WB position (standing) or a NWB position (side-lying and seated).

Standing position

Information regarding the gluteal activation for the standing position can be observed in Table 1. Eighteen studies used this position with twenty-six exercise variations and 363 subjects. The most commonly studied exercise variation was the lateral step up (126 subjects). The highest Gmax (113.8 $\pm$ 89.5 % MVIC) activation occurred in the lateral step up,[14] however, when averaged from six studies, the activation level was 49.6 $\pm$ 15 % MVIC. The highest Gmed (101 $\pm$ 7 % MVIC) activation occurred in the standing hip abduction Thera band at ankle (Borg (Borg Rating of Perceived Exertion CR10) ≥7 load)[46] When all data was pooled, the average Gmax activation was 34.7 $\pm$ 14.3 % MVIC and the average Gmed activation was 47.2 $\pm$ 17.2 % MVIC for the standing exercise variations (see Table 4).

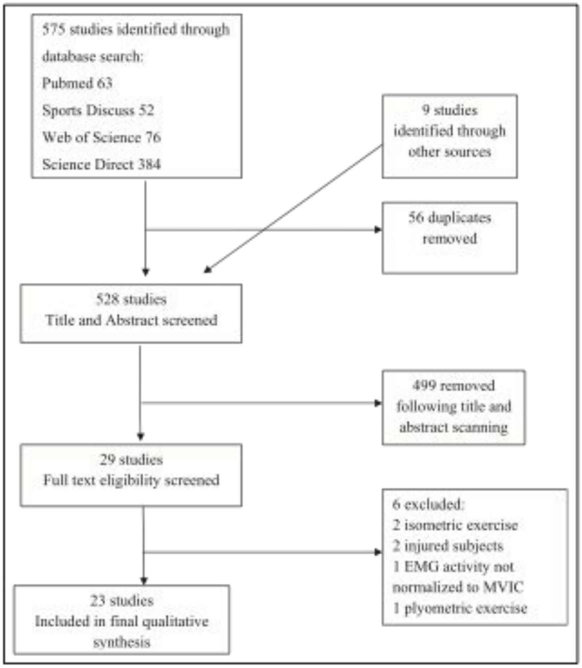

Figure 1. *Flow chart of information through the different phases of the systematic review*

Side-lying position

Details of gluteal activation for the side-lying position can be observed in Table 2. Twelve studies used this position with twenty-two different exercise variations and 244 subjects. The most commonly studied exercise variation was the side-lying hip abduction (197 subjects). The highest Gmax (72.8 % MVIC) and Gmed (103 % MVIC) activation was associated with the side bridge with abduction dominant leg (DL) down exercise.[51] When all data was pooled the average Gmax activation was 30.4 ± 23.8 % MVIC and the average Gmed activation was 41.9 ± 16.5 % MVIC for the side lying exercise variations (see Table 4).

Seated Position

Specifics regarding gluteal activation for the seated position are detailed in Table 3. One study used this position with four different exercise variations and sixteen subjects. The highest Gmax (70.8 ± 11 % MVIC) and Gmed (80 ± 8 % MVIC) activation was associated with the seated hip abduction machine (Borg ≥7 load).[40] When all data was pooled, the average Gmax activation was 66.7 ± 10 % MVIC and the average Gmed activation was 65.2 ± 7.2 % MVIC for the seated variations (see Table 4).

Summary of positions

Details of gluteal activation for all positions are summarized in Table 4. For both Gmax and Gmed, the standing position produced a higher activation compared to the side-lying position whilst the seated position produced the highest average activation for both Gmax (66.7 ± 10 % MVIC) and Gmed (65.2 ± 7.2 % MVIC). While the seated position produced the highest activation, only one study used exercises in that position.

Exercise EMG Activity Level (% MVIC)

The magnitude of mean gluteal activation is stratified into the four levels of activity[43-45] in Figures 2-5. This classification scheme provides a means

Table 1. *Comparison of muscle activation in the Gluteus Maximus and Gluteus Medius for all standing exercises. Values given as the mean and the standard deviation*

Exercise	Number of Studies	Number of Subjects	Range % MVIC		Average % MVIC	
			Gmax	Gmed	Gmax	Gmed
Cross over step up	1	15	103 ± 63.6	57.6 ±19.5	103 ± 63.6	57.6 ±19.5
Lateral lunge	2	61	41 ± 20 – 12± 3	39 ± 19 - 13 ± 2	26.5 ± 11.5	26 ± 10.5
Lateral stepping band at foot	1	9	8± 5	35 ± 10	8± 5	35 ± 10
Lateral stepping band at ankle	3	50	27 ± 16 - 6 ± 4	61 ± 34 - 29 ± 9	15 ± 9.3	24 ± 20
Lateral stepping band at knee	2	29	27.4 ± 16.4- 5 ± 3	30.2 ± 15.2 - 24 ± 9	16.2 ± 9.7	27.8 ± 12.1
Lateral stepping , hip internally rotated band at ankle	1	21	13 ± 9.1	43.8 ± 27	13 ± 9.1	43.8 ± 27
Lateral stepping, hip externally rotated band at ankle	1	21	27.3 ± 18.1	27.3 ± 18.1	27.3 ± 18.1	27.3± 18.1
Lateral step up	6	126	113.8 ± 9.5 - 29± 13	59.8 – 18 ± 18	49.6 ± 15	41.4 ± 16.7
Lateral step up with 10% BM	1	13	23 ± 11	-	23 ± 11	-
Lateral step up with 25 %BM	1	19	20 ± 8	-	20 ± 8	-
Monster walk band at foot	1	9	6 ± 3	27 ± 10	6 ± 3	27 ± 10
Monster walk band at ankle	1	9	5 ± 2	25 ± 10	5 ± 2	25 ± 10
Monster walk band at knee	1	9	4 ± 2	19 ± 9	4 ± 2	19 ± 9
Pelvic drop (standing hip abduction/ adduction)	3	49	17 ± 15	57 ± 32 - 29.2 ± 10.6	17 ± 15	49.3 ± 25.6
Shoulder dump (overhead throwing movement into hip rotation)	1	30	28 ± 3	-	28 ± 3	-

Table 1. *(Continued) Comparison of muscle activation in the Gluteus Maximus and Gluteus Medius for all standing exercises. Values given as the mean and the standard deviation*

Exercise	Number of Studies	Number of Subjects	Range % MVIC		Average % MVIC	
			Gmax	Gmed	Gmax	Gmed
Standing hip abduction	2	29	-	33 ± 23 - 30 ± 21	-	31.5 ± 22
Standing hip abduction with hip and knee in 20° of flexion	1	16	-	28 ± 21	-	28 ± 21
Standing hip abduction with 3% BM	1	16	-	42 ± 27	-	42 ± 27
Standing hip abduction with 3% BM and hip and knee in 20° of flexion	1	16	-	46 ± 34	-	46 ± 34
Standing hip abduction band at ankle (Borg ≤2)	1	16	59 ± 10	73 ± 7	59 ± 10	73± 7
Standing hip abduction band at ankle (Borg ≤2-<5)	1	16	65 ± 9	88 ± 7	65 ± 9	88± 7
Standing hip abduction band at ankle (Borg ≤5-<7)	1	16	68± 11	93± 8	68± 11	93± 8
Standing hip abduction band at ankle (Borg ≥7)	1	16	73 ± 25	101 ± 7	73 ± 25	101± 7
Standing hip abduction with band at ankle	1	26	16.6 ±10.8	52.9 ± 17.6	16.6 ±10.8	52.9± 17.6
Rotational single leg squat	1	9	79 ± 45	68 ± 15	79 ± 45	68 ± 15
Transverse lunge	2	30	58 ± 23- 49± 20,	68 ± 62 - 48±21	53.5 ± 26	58 ± 45.5

BM = Body Mass **Gmax** = Gluteus Maximus **Gmed** = Gluteus Medius **MVIC** = Maximum voluntary isometric contraction **Borg** = Borg Rating of Perceived Exertion

Table 2. *Comparison of muscle activation in the Gluteus Maximus and Gluteus Medius for all side lying exercises. Values given as the mean and the standard deviation*

Exercise	Number of Studies	Number of Subjects	Range% MVIC		Average % MVIC	
			Gmax	Gmed	Gmax	Gmed
Clam shell with pelvic belt	1	20	33 ± 23	21 ±12	33 ± 23	21 ± 12
Clam shell with band at knee	1	20	43.6 ± 26.1	26.9 ± 18	43.6 ± 26.1	26.9 ± 18
Clam shell with 5% BM	1	20	34 ± 25	33 ± 17	34 ± 25	33 ± 17
Clam shell 1	2	36	53.1–20.5±18.4	47.2-16.4 ± 11.3	36.8	31.5
Clam shell 2	1	26	12.3	62.4	12.3	62.4
Clam shell 3	1	26	26.6	67.6	26.6	67.6
Clam shell 4	1	26	26.2	76.8	26.2	76.8
Clam shell PNHIP0	2	27	15	18 -9.4	15	13.7
Clam shell PNHIP30	2	38	34 ± 27 - 17	40 ± 38 - 22	25.5	31
Clam shell PNHIP60	3	58	39 ± 34 - 20	38 ± 29 - 23	23.6 ± 26	24 ± 20
Clam shell PRHIP0	1	17	10	12	10	12
Clam shell PRHIP30	1	17	9	13	9	13
Clam shell PRHIP60	1	17	12	18	12	18
Side bridge with abduction DL down	1	26	72.8	103	72.8	103
Side bridge with abduction DL up	1	26	70.9	88.8	70.9	88.8
Side lying hip abduction	9	197	51.1 – 21 ± 16	81.2 - 26.8±12.8	32.4 ± 17	45.2 ± 16.2
Side lying hip abduction with 5% BM	1	20	25.3 ± 24.6	79.1 ± 29.9	25.3 ± 24 6	79.1 ± 29 9

Table 2. *(Continued) Comparison of muscle activation in the Gluteus Maximus and Gluteus Medius for all side lying exercises. Values given as the mean and the standard deviation*

Exercise	Number of Studies	Number of Subjects	Range% MVIC		Average % MVIC	
			Gmax	Gmed	Gmax	Gmed
Side-lying hip abduction with 5% BM and external rotation	1	20	31.7 ± 24.1	54.3 ± 24.8	31.7 ± 24.1	54.3 ± 24.8
Side-lying hip abduction with pelvic belt	1	20	37.3 ± 24.9	34.2 ± 15.9	37.3 ± 24.9	34.2 ± 15.9
Side-lying hip abduction against a wall	1	10	-	25.9 ± 5.65	-	25.9 ± 5.65
Side-lying hip abduction Internal rotation	2	30	-	35.3 ± 12.5 - 26.7 ± 6.7	-	31.7 ± 9.6
Side-lying hip abduction External rotation	2	30	-	45.3 ± 20.5 - 13 ± 4.25	-	29.1 ± 12.5

BM = Body Mass **DL** = Dominant Leg **Gmax** = Gluteus Maximus **Gmed** = Gluteus Medius **MVIC**= Maximum voluntary isometric contraction **Clam Shell 1** = Side-lying with hips flexed to 45°. Externally rotate top leg **Clam Shell 2** = same as Clam 1 but internally rotate the top leg (knees together) **Clam Shell 3** = Top thigh raised to parallel to table with hip in neutral rotation and 45 ° of flexion. Top leg then internally rotated. Knee height remains the same throughout the entire movement. **Clam Shell 4** = Same as 3 except the top leg is in extension **Clam shell PNHIP0** = pelvis neutral, hip in 0° of flexion **Clam shell PNHIP30** = pelvis neutral, hip in 30° of flexion **Clam shell PNHIP60** = pelvis neutral, hip in 60° of flexion **Clam shell PRHIP0** = pelvis reclined, hip in 0° of flexion **Clam shell PRHIP30** = pelvis reclined, hip in 30° of flexion **Clam shell PRHIP60** = pelvis reclined, hip in 60° of flexion **Borg** = Borg Rating of Perceived Exertion CR10

Table 3. *Comparison of muscle activition in the Gluteus Maximus and Gluteus Medius for all seated exercises. Values given as the mean and the standard deviation*

Exercise	Number of Studies	Number of Subjects	Range % MVIC		Average % MVIC	
			Gmax	Gmed	Gmax	Gmed
Seated hip abduction machine (Borg ≤2)	1	16	67 ± 9	53 ± 7	67 ± 9	53 ± 7
Seated hip abduction machine (Borg ≤2- <5)	1	16	65 ± 10	61 ± 7	65 ± 10	61 ± 7
Seated hip abduction machine (Borg ≤5- <7)	1	16	69 ± 10	67 ± 7	69 ± 10	67 ± 7
Seated hip abduction machine (Borg ≥7)	1	16	70 ±11	80 ± 8	70 ±11	80 ± 8

Gmax = Gluteus Maximus **Gmed** = Gluteus Medius **MVIC**= Maximum voluntary isometric contraction **Borg** = Borg Rating of Perceived Exertion CR10

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

Exercise Position	Standing	Side-lying	Seated
Number of Studies	17	12	1
Number of Subjects	363	244	16
Number of Exercises	26	22	4
Gmax Average % MVIC	34.7 ± 14.3	30.4 ± 23.8	68.8 ± 10
Gmed Average % MVIC	47.2 ± 17.4	41.9 ± 16.5	65.3 ± 7.5

Gmax = Gluteus Maximus **Gmed** = Gluteus Medius **MVIC**= Maximum voluntary isometric contraction

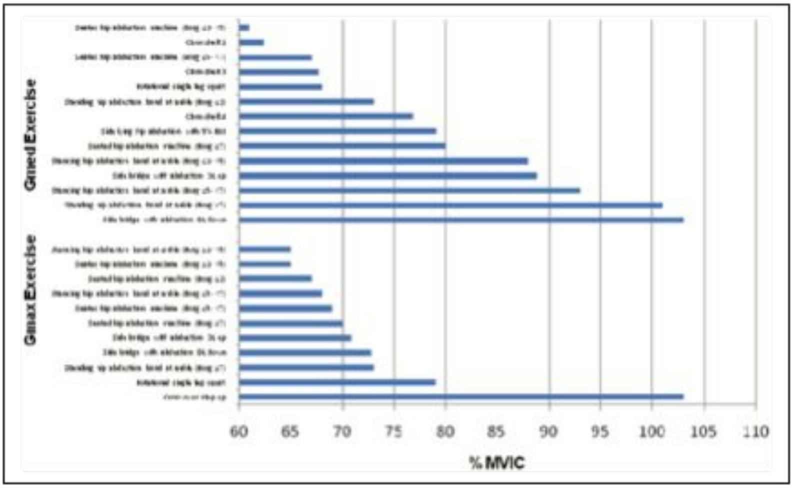

Figure 2. *Mean Gluteus Maximus (Gmax) and Gluteus Medius (Gmed) exercises with very high activation (>60% of averaged EMG/MVIC).*

BM = *Body mass* **MVIC** = *Maximum voluntary isometric contraction* **Borg** = *Borg Rating of Perceived Exertion CR10* **DL** = *Dominant leg* **Clam Shell 2** = *Side-lying with hips flexed at 45°. Internally rotate the top leg (knees together)* **Clam Shell 3** = *Top thigh raised to parallel to table with hip in neutral rotation and 45° of flexion. Top leg then internally rotated. Knee height remains the same throughout the entire movement* **Clam Shell 4** = *Same as 3 except the top leg is in extensio*

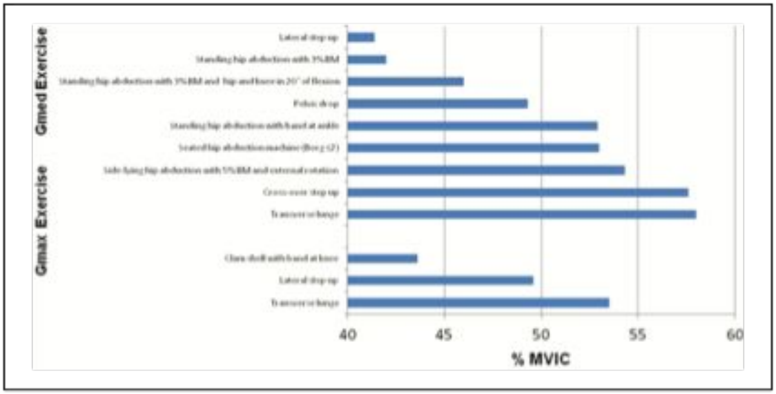

Figure 3. *Mean Gluteus Maximus (Gmax) and Gluteus Medius (Gmed) exercises with high activation (>41 – 60% of averaged EMG/MVIC).*

BM = *Body mass* **MVIC** = *Maximum voluntary isometric contraction* **Borg** = *Borg Rating of Perceived Exertion CR10*

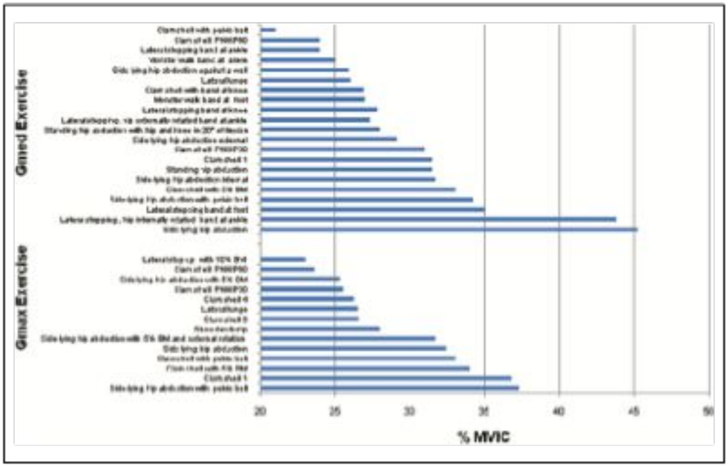

Figure 4. *Mean Gluteus Maximus (Gmax) and Gluteus Medius (Gmed) exercises with moderate (>21 – 40% of averaged EMG/MVIC).*

***BM** = Body mass **MVIC** = Maximum voluntary isometric contraction **Borg** = Borg Rating of Perceived Exertion CR10 **DL** = Dominant leg **Clam Shell 1** = Side-lying with hips flexed at 45°. Externally rotate top **Clam Shell 3** = Top thigh raised to parallel to table with hip in neutral rotation and 45° of flexion. Top leg then internally rotated. Knee height remains the same throughout the entire movement **Clam Shell 4** = Same as 3 except the top leg is in extension **PNHIP0** = pelvis neutral, hip in 0° of flexion **Clam shell PNHIP30** = pelvis neutral, hip in 30° of flexion **Clam shell PNHIP60** = pelvis neutral, hip in 60° of flexion*

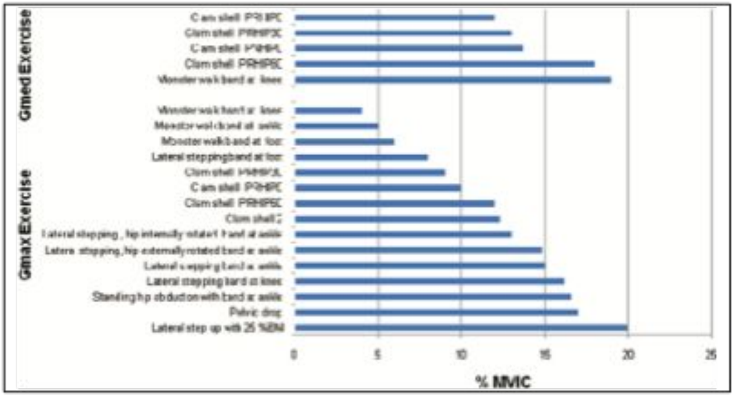

Figure 5. *Mean Gluteus Maximus (Gmax) and Gluteus Medius (Gmed) exercises with low activation (0-20% of averaged EMG/MVIC).*

***BM** = Body Mass **MVIC** = Maximum voluntary isometric contraction **Clam Shell 2** = Side-lying with hips flexed at 45°. Internally rotate the top leg (knees together) **Clam shell PNHIP0** = pelvis neutral, hip in 0° of flexion **Clam shell PRHIP0** = pelvis reclined, hip in 0° of flexion **Clam shell PRHIP30** = pelvis reclined, hip in 30° of flexion **Clam shell PRHIP60** = pelvis reclined, hip in 60° of flexion* by which the practitioner can select exercises, that match the strength status of their client/athlete and also provides a means by which strengthening of the gluteals can be progressively overloaded in a systematic fashion.

Very High EMG Activity Exercise

The very high activity exercises (Gmax: 11 exercises, Gmed: 14 exercises) can be observed in Figure 2. The cross over step up exercise produced the highest Gmax activation (103 ± 63.6 % MVIC), while the side bridge with hip abduction DL down produced the highest Gmed activation (103% MVIC).

High EMG Activity Exercise

The high activity exercises (Gmax: 4 exercises, Gmed: 8 exercises) are detailed in Figure 3. This tier had the fewest number of exercises (12) compared to the other activation tiers with 9 of the exercises performed in the standing position.

Moderate EMG Activity Exercise

Moderate activity exercises (Gmax: 21 exercises, Gmed: 14 exercises) of the gluteal musculature can be viewed in Figure 4. This tier had the highest number of exercises (total 35).

Low EMG Activity Exercise

The low activation exercises (Gmax: 15 exercises, Gmed: 5 exercises) are shown in Figure 5. Exercises in this tier corresponded considerably more to Gmax activation than Gmed. Three variations of the monster walk exercise required the least amount of activation for the Gmax (range 4-6 % MVIC) while four variations of the clam shell exercise elicited the lowest amount of activation for the Gmed (ranging from 12-18 % MVIC).

DISCUSSION

The results of this systematic review indicate that EMG activation (% MVIC) of the Gmax and Gmed musculature from hip abduction and external rotation exercises varied greatly depending on the position and complexity of the movement. Andersen et al[38] proposed that exercises with higher % MVIC values are necessary for strength gains. A factor in strength progression is exercise intensity, indicated through EMG data with a greater % MVIC requiring greater motor control and joint stabilisation.[38] Therefore, for enhancing muscular strength in a rehabilitation setting, it is valuable to be aware of the level of muscle activation an exercise elicits. Moreover, Boren et al[52] noted that by knowing a muscles % MVIC during various exercises, the strengthening potential can be inferred. Exercises performed in a WB position produced a greater % MVIC compared to a NWB position for both muscle groups, with Gmed activity levels higher than Gmax in both positions. The top three Gmax and two of the top three Gmed EMG activity exercises were performed in a WB position suggesting that standing exercises imposed greater demands of the musculature and changes to the base of support can affect the activity level of the Gmax and Gmed.

Although several exercises in the very high tier are demanding, thus potentially inappropriate for beginners or weaker individuals due to the high stability requirements, the clam shell exercises versions 2 – 4 (ranging 62.4-76.8 % MVIC) can be used to elicit strengthening of the Gmed as the side-lying position provides stabilization. Clam shell version 2 requires internal hip rotation from a side-lying position at 45° hip flexion, version 3 has internal hip rotation performed from the top leg which is raised and held in an abducted position, whilst version 4 is the same as version 3 but the top leg is in extension. Moreover, individuals who are unable to perform WB exercises can benefit from performing clam shell exercises and other NWB side-lying exercises. The side lying abduction exercise is commonly prescribed by practitioners, evidenced by being used in nine studies with EMG activity ranging from 21.3 - 51.1 % MVIC for the Gmax and 26.8 - 81.2 % MVIC for the Gmed. The variance in EMG activity can be most likely attributed to differing testing positions such as the angle at which abduction was maintained, pelvis position and whether the leg abducted was in hip flexion or hip extension. Three other side-lying abduction exercises produced moderate activation of the Gmax (range 25.3 – 37.3 % MVIC) noting its role as a secondary hip abductor, while six variations of the clam exercise highlight the Gmax's role as a lateral rotator (range 26.2 -39 % MVIC).

The greater demands of the step up exercises as demonstrated by greater Gmed activity, highlight the synergist role of the Gmed in maintaining pelvis and knee stability (cross over step up 57.6 ± 19.5 and mean lateral step up 41.4 ± 16.7 % MVIC). Variations in EMG activation during the lateral step up exercise may be attributed to an individual's familiarity with the complexity of the movement and the height of the box with Gmed activity ranging from 18 – 59.8 % MVIC and Gmax ranging from 29 to 113 % MVIC. This is exemplified by the highest box height 45.7cm used by Simenz et al.[14] resulting in the highest Gmax activity of 113 % MVIC. Compared to the step-up exercises, the pelvic drop (standing hip abduction/adduction) exercise may be considered a simpler exercise to be taught and implemented, yet it produced high Gmed activation (mean 49.3 ± 25.6 and highest 57.6 ± 19.5 % MVIC) due to the pelvis-on-femur adduction and abduction control, as noted by Reiman et al.[3]

Though often prescribed to target the Gmed, the standing hip abduction exercise with Thera band attached to the ankle produced a high level of Gmax activation (59 % MVIC) highlighting its role as a secondary hip abductor. Three variations of the monster walk exercise required the least amount of activation for the Gmax (range 4-6 % MVIC) while four variations of the clam shell exercise elicited the lowest amount of activation for the Gmed (ranging from 12-18 % MVIC). Of consideration to practitioners is that during the monster walk exercise, distal band placement resulted in greater activation of Gmax and Gmed, as compared to proximal band placement.

Interpretation Limitations

The reader needs to be cognisant of a number of limitations that affect interpretation, namely that the methodological approaches varied greatly between the twenty-three studies (see Appendix 1). For example, some studies used different exercise positions for determination of the MVIC, which could dramatically impact normalized levels of gluteal activation. This is especially important in the case of the Gmax, since Worrell et al[48] showed that the level of maximal activation is highly dependent on the hip angle. Moreover, the placement of the electrodes on the Gmax and Gmed differed between some studies. All studies used surface electrodes, with the exception of Selkowitz et al[58] who used indwelling electrodes. To normalize the EMG signals recorded for each muscle, different studies used different approaches e.g. root mean square of 3 trials or average EMG of 3 trials. Moreover, the EMG's signal moving window varied from 11.7 to 5000 milliseconds. Furthermore, data was extrapolated from the Figures of Cambridge et al., [53] Webster and Gribble, [59] Oliver [58] and Willcox and Buden,[60] which potentially introduces measurement error. Where concentric and eccentric data was provided by Philippon et al[10] and Simenz et al,[14] the data was averaged and presented as such in this review. In order to accurately compare EMG activity between two studies, at the very least, their MVIC positions, electrode site placements, data processing, and amplitude presentations should be identical, and other variables such as range of motion, relative load, effort, tempo, gender, age, and training status should be similar when possible.

Several studies investigated the same exercise, however, differences in the way the exercises were performed need to be considered when analysing the findings. For example, the step up height used for lateral step up exercise ranged between 15 to 45.7cm, therefore, differing levels of EMG activation would be an expected outcome. Moreover, the thickness and therefore level of resistance for the rubber tubing / band resistance exercises is another consideration when comparing findings. Additional limitations related to this review pertain to many exercises that would meet the inclusion criteria but have yet to undergo EMG examination.

Future research should be conducted to compare a wide variety of Gmax and Gmed exercises, perhaps the exercise that top the charts in this review, under the same testing conditions (ie: MVIC position, electrode site placement, data processing, amplitude presentation), to verify that the data in this review are accurate. Finally, this review summarises information obtained from healthy subjects; therefore, vigilance is necessary when extrapolating these findings to patients with pathology.

CONCLUSION AND PRACTICAL APPLICATION

The purpose of this systematic review was to quantify the EMG activity of the Gmax and Gmed musculature during hip abduction and hip external rotation exercises. It would seem that EMG activity levels can be affected by changes in body position (WB vs. NWB) and the complexity of the exercise. EMG activity for Gmax ranged from 4 to 113 % MVIC and Gmed ranged from 12 to 103 % MVIC. Exercises with greater movement complexity, e.g. exercises such as the lateral step-up where the body must change the angles of more than one joint while performing the action, were found to elicit greater % MVIC for both Gmax and Gmed. Exercises performed WB produced a greater % MVIC for both Gmax and Gmed compared to NWB. Although the NWB seated position was found to have the greatest activity levels, only one study assessed this position making analysis and comparison limited.

The higher EMG activation found in WB movements is explained by Reiman et al[3] who suggested that when an exercise pattern imposes greater movement demands, the Gmax and Gmed are required to maintain a level pelvis position, through hip abduction, and minimize knee valgus, through hip external rotation. Hence, practitioners ought to consider trunk position in relation to the base of support, in addition to the direction of movement when applying a progressive strengthening program.[3] Individuals who have difficulty performing WB exercises can benefit from using NWB side-lying or seated exercises to strengthen the gluteal musculature. When strengthening a weaker muscle or muscle group, practitioners may wish to prescribe a gradual and progressive exercise program to ensure the targeted area is developed. This may be of importance if individuals seek and implement a compensatory movement pattern when faced with weakness or dysfunction. Individuals may benefit from being prescribed exercises that they can perform with good technique without substitution. Subsequently, once this can be achieved exercise difficulty can be progressed with more difficult exercises.

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Appendix 1. *Summary of the 23 studies reviewed with EMG activation (%MVIC) values given as the mean and the standard deviation*

Author and Date	Subjects (Sex, age, height, mass)	Methodology (MVIC position, data processing, and amplitude presentation)	Exercises	EMG Activation (%MVIC)
Worrell et al[48]	Group 1: 13 (6 males, 7 females) 22 ± 8.6 years, 1.71 ± 0.15 m, 69.1 ± 14.1 kg Group 2: 19 (13 males, 6 females) 27.5 ± 5 years, 1.75 ± 0.09 m, 73.3 ± 15.3 kg	Gmax : Prone hip extension against manual resistance at 0° of hip flexion RMS: 11.7-millisecond moving window	Group 1 Lateral step up (+10 % BM) Lateral step up (unloaded) Group 2 Lateral step up (+25 % BM) Lateral step up (unloaded)	 Gmax 23 ± 11 Gmax 20 ± 11 Gmax 20 ± 8 Gmax 16 ± 7
Bolga and Uhl[21]	16 (8 males, 8 females) 27 ± 5 years, 1.7 ± 0.2 m, 76 ± 15 kg	Gmed: Side lying hip abduction at 25° against a strap RMS: 500-millisecond moving window	Side-lying hip abduction Standing hip abduction Standing hip abduction (3% BM) Standing abduction (BM) with hips and knees in 20° of flexion Standing hip abduction (3% BM) with hip and knee in 20° of flexion Pelvic drop	Gmed 42 ± 23 Gmed 33 ± 23 Gmed 42 ± 27 Gmed 28 ± 21 Gmed 46 ± 34 Gmed 57 ± 32
Ayotte et al[31]	23 (16 males, 7 females) 31.2 ± 5.8 years, 1.73 ± 0.11 m, 77 ± 13.9 kg	Gmax: Supine hip extension against a fixed pad at 30° hip flexion Gmed: Side lying hip abduction at 25° against a fixed pad Average EMG of 3 trails	Lateral step up	Gmax 56 ± 29, Gmed 18 ± 18
Bolga and Uhl[19]	13 (7 males, 6 females) 24 ± 7 years, 1.6 ± 0.2 m, 78 ± 14 kg	Gmed: Side lying hip abduction at 25° against a strap RMS: 500-millisecond moving window	Side-lying hip abduction Standing hip abduction Standing abduction with hip and knee in 20° of flexion Pelvic drop	Gmed 40 ± 22 Gmed 30 ± 21 Gmed 27 ± 20 Gmed 54 ± 30
Ekstorm et al[30]	30 (19 males, 11 females) 27 ± 8 years, 1.76 ± 0.8 m, 74 ± 11 kg	Gmax: Prone hip extension against manual resistance with the knee flexed at 90° Gmed: Side lying hip abduction to end range against manual resistance RMS: 20-millisecond moving window	Side-lying hip abduction Lateral step up	Gmax 21 ± 16, Gmed 39 ± 7 Gmax 2 9± 13, Gmed 43 ±18
DiStefano et al[42]	21 (9 males, 12 females) 22 ± 3 years, 1.71 ± 0.11 m, 70.4 ± 15.3 kg	Gmax: Prone hip extension against manual resistance with knee flexed at 90° Gmed: Side lying hip abduction at 25° against a strap Average EMG of 3 trials	Side-lying hip abduction Lateral stepping band at ankle Lateral lunge Transverse lunge Clam shell PNHIP30 Clam shell PNHIP60	Gmax 39 ± 18, Gmed 81 ± 2 Gmax 27 ±16, Gmed 6 1 ± 34 Gmax 41 ± 20, Gmed 39 ± 19 Gmax 49 ± 20, Gmed 48 ± 21 Gmax 34 ± 27, Gmed 40 ± 38 Gmax 39 ± 34, Gmed 38 ± 29
O'Sullivan et al[23]	16 (7 males, 8 females) 22 ± 4 years, 1.70 ± 0.1 m, 68 ± 12 kg	Gmed: the highest EMG reading from all three hip abduction movements against a fixed pad: 1) standing with the hip at 30° abduction 2) internal and 3) external rotation was tested prone with the hip in neutral rotation and the knee flexed at 90°. RMS: 150-millisecond moving window	Pelvic drop	Gmed 29.2 ± 10.6
Park et al[25]	31 (15 males, 16 females) 19.2 ± 1.44 years, 1.67 ± 0.08 m, 60.6 ± 10 kg	Gmed: Side lying hip abduction against manual resistance RMS: 5000-millisecond moving window	Side-lying hip abduction Side-lying hip abduction with pelvic belt	Gmed 26.8 ± 12.8 Gmed 35 ± 18.2

Appendix 1. *(Continued) Summary of the 23 studies reviewed with EMG activation (%MVIC) values given as the mean and the standard deviation*

Boren et al[51]	26 (Anthropometrical details not provided)	Gmax: Prone hip extension against a strap with the knee flexed at 90° Gmed: Side lying hip abduction at 10° against a strap RMS: 50-millisecond moving window	Side-lying hip abduction Side bridge with abduction DL down Side bridge with abduction DL up Lateral step up Clam shell 1 Clam shell 2 Clam shell 3 Clam shell 4	Gmax 51.1, Gmed 62.9 Gmax 72.8, Gmed 103 Gmax 70.9, Gmed 88.8 Gmax 63.8, Gmed 59.8 Gmax 53.1, Gmed 47.2 Gmax 12.3, Gmed 62.4 Gmax 26.6, Gmed 67.6 Gmax 26.2, Gmed 76.8
Philippon et al.[18]	10 (5 males, 5 females) 28.7 ± 2.2 years, 1.72 ± 0.04 m, 67.4 ± 4.3 kg	Gmed: Standing hip abduction with external rotation against manual resistance RMS: 50-millisecond moving window	Clam shell Clam shell PNHIP0 Side-lying hip abduction – internal rotation Side-lying hip abduction – external rotation Side-lying hip abduction against a wall	Gmed 13.9 ± 3.6 Gmed 9.4 ± 2.75 Gmed 26.7 ± 6.7 Gmed 13 ± 4.25 Gmed 25.9 ± 5.65
Bouillon et al[52]	40 (20 males, 20 females) 22 ± 1 years, 1.7 ± 0.01 m, 65 ± 13 kg	Gmax: Prone hip extension against manual resistance with the knee flexed at 90° Gm: Side lying hip abduction against manual resistance RMS: 300-millisecond moving	Lateral lunge	Gmax 12 ± 3, Gmed 13 ± 2
		window		
Cambridge et al[53]	9 males, 22 ± 2 years, 1.81 ± 0.92 m, 85.8 ±15.4 kg	Gmax : Prone hip extension in Biering–Sorensen position against manual resistance Gmed: Side lying hip abduction against manual resistance Average EMG	Lateral stepping band at foot Lateral stepping band at ankle Lateral stepping band at knee Monster walk band at foot Monster walk band at ankle Monster walk band at knee	Gmax 8± 5, Gmed 35 ± 10 Gmax 6 ± 4, Gmed 29 ± 9 Gmax 5 ± 3, Gmed 24 ± 9 Gmax 6 ± 3, Gmed 27 ± 10 Gmax 5 ± 2, Gmed 25 ± 10 Gmax 4 ± 2, Gmed 19 ± 9
McBeth et al[54]	20 (9 males, 11 females) 26.3 ± 6 years, 1.71 ± 0.06 m, 64 ± 6.8 kg	Gmax : Prone hip extension against manual resistance with the knee flexed at 90° Gmed: Side lying hip abduction at 35° against manual resistance RMS: 20-milliseconds moving window	Side-lying hip abduction (5% BM) Side-lying hip abduction – external rotation (5% BM) Clam shell (5% BM)	Gmax 25.3 ± 24.6, Gmed 79.1 ± 29.9 Gmax 31.7 ± 24.1, Gmed 54.3 ± 24.8 Gmax 34.2 ± 24.8, Gmed 32.6 ±16.9
Simenz et al[14]	15 females, 20.8 ± 1.56 years, 1.66 ± 0.07 m, 64 ± 6.92 kg	Gmax : Prone hip extension at 70° hip flexion on a decline bench Gmed: Side lying hip abduction at 25° against fixed resistance RMS: 125-milliseconds moving window	Lateral step up Cross over step up	GM 113 ± 89.5,Gm 45 ±14 GM 103 ± 63.6,Gm 57.6 ±19.5
Brandt et al.[46]	16 females, 45.7 ± 8.6 years, 1.65 ± 0.52 m, 61.8 ± 7.2 kg	Gmax: Prone hip extension against manual resistance with the knee flexed at 90° Gmed: Supine with hip abduction at	Standing hip abduction band at ankle load: light (Borg ≤2) Standing hip abduction band at ankle load: moderate Borg ≤2- <5)	Gmax 59 ± 10, Gmed 73 ± 7 Gmax 65 ± 9, Gmed 88 ± 7

Appendix 1. *(Continued) Summary of the 23 studies reviewed with EMG activation (%MVIC) values given as the mean and the standard deviation*

		10° and pressing the knees outwards against a rigid band RMS: 500 milliseconds moving window	Standing hip abduction band at ankle load: heavy (Borg ≤5- <7) Standing hip abduction band @ ankle load: near maximum (Borg ≥7) Seated hip abduction machine load: light (Borg ≤2) Seated hip abduction machine load: moderate (Borg ≤2- <5) Seated hip abduction machine load: heavy (Borg ≤5- <7) Seated hip abduction machine load: near maximum (Borg ≥7)	Gmax 68 ± 11, Gmed 93 ± 8 Gmax 73 ± 25, Gmed101 ± 7 Gmax 67 ±11, Gmed 53 ± 7 Gmax 65 ± 10, Gmed 61 ± 7 Gmax 69 ± 10, Gmed 67 ± 7 Gmax 70 ± 11, Gmed 80 ± 8
Lee, J et al[55]	20, 22.3 ± 1.9 years, 1.69 ± 0.72 m, 66 ± 12.4 kg	Gmed: Side-lying hip abduction against manual resistance RMS: 50 milliseconds moving window	Side-lying hip abduction Side-lying hip abduction – external rotation Side-lying hip abduction – internal rotation	Gmed 34.2 ± 11.8 Gmed 35.3 ± 12.5 Gmed 45.3 ± 20.5
Lee, K et al[56]	20 males, 22.9 ± 2.1 years, 1.74 ± 0.39 m, 70 ± 6.2 kg	Gmed: Side lying hip abduction at 25° against a strap RMS	Side-lying hip abduction Side-lying hip abduction with pelvic belt Clam shell 1 Clam shell with pelvic belt	Gmax 27.6± 19, Gmed 38±21.6 Gmax 37.3± 24.9, Gmed 34.2 ±15.9 Gmax 20.5± 18.4, Gmed 16.4 ± 11.3 Gmax 33.1± 23.2, Gmed 21.7 ±12.6
Oliver et al[57]	30, 23.5 ± 1.34 years, 1.74 ± 0.11 m, 76.6 ± 16.9 kg	Gmax : Prone hip extension against manual resistance with the knee flexed at 90° RMS: 100-milliseconds moving window	Shoulder dump	Gmax 28± 3
Selkowtiz et al[58]	20 (10 males, 10 females) 27.9 ± 6.2 years	Fine Wire Electrodes EMG Gmax : Prone hip extension against a strap with the knee flexed at 90° Gmed: Side lying hip abduction at 30° against a strap RMS: 75-milliseconds moving window	Side-lying hip abduction Clam shell with band at knee Lateral stepping band at knee Pelvic Drop	Gmax 23.7 ±15.3, Gmed 43.5 ± 14.9 Gmax 43.6 ±26.1, Gmed 26.9 ± 18 Gmax 27.4 ±16.4, Gmed 30.2 ± 15.7 Gmax 17.7 ±15.2, Gmed 37.7 ± 15.1
Webster and Gribble[59]	9 (1 males, 8 females) 22.9 ± 4.5 years, 1.64 ± 0.65 m, 65.4 ±10kg	Gmax : Prone hip extension against manual resistance with the knee flexed at 90° Gmed: Side lying hip abduction against manual resistance Average EMG of 3 trails	Rotation single leg squat Transverse lunge	Gmax 78 ± 45, Gmed 68 ± 15 Gmax 58 ± 32, Gmed 68 ± 62
Willcox and Buden[60]	17(10 males, 7 females) 24 ± 4 years, 1.74 ± 0.6 m, 69 ±12kg	Gmax: Prone hip extension against manual resistance with the knee flexed at 90° Gmed: Side lying hip abduction against manual resistance RMS: 150-milliseconds moving window	Clam shell PNHIP0 Clam shell PNHIP30 Clam shell PNHIP60 Clam shell PRHIP0 Clam shell PRHIP30 Clam shell PRHIP60	Gmax 15, Gmed 18 Gmax 17, Gmed 22 Gmax 20, Gmed 23 Gmax 10, Gmed 12 Gmax 9, Gmed 13 Gmax 12, Gmed 18
Youdas et al[61]	21 (10 males, 11 females) 25.2 ± 3.1 years, 1.8 ± 0.1 m, 82.2 ±7.9kg	Gmax: Prone position, a pillow placed under the pelvis to provide 10°-15° of hip flexion, knee flexed at 90°, hip extension against manual resistance Gmed: Side lying hip abduction at 30° against manual resistance RMS: 125-milliseconds moving window	Lateral stepping band at ankle Lateral stepping, hip internally rotated stance band at ankle Lateral stepping, hip externally rotated stance band at ankle	Gmax 12.1 ± 8.4, Gmed 32.8 ± 21.9 Gmax 13 ± 9.1, Gmed 43.8 ± 27 Gmax 14.8 ±10.7, Gmed 27.3 ± 18.1
Youdas et al[45]	26 (13 males, 13 females) 25 ± 2 years, 1.75 ± 0.6 m, 72.5 ±10.1kg	Gmax: Prone position, a pillow placed under the pelvis to provide 10°-15° of hip flexion, knee flexed at 90°, hip extension against manual resistance Gmed: Side lying hip abduction at 30° against manual resistance RMS: 125-milliseconds moving window	Standing hip abduction with band at ankle	Gmax 16.6 ± 10.8, Gmed 52.9 ± 17.6

BM = Body Mass **DL** = Dominant Leg **Gmax** = Gleteus Maximus **Gmed** = Gleteus Medius **Clam Shell 1** = Side-lying with hips flexed at 45°. Externally rotate top leg **Clam Shell 2** = Same as Clam 1 but internally rotate the top leg (knees together) **Clam Shell 3** = Top thigh raised to parallel to table with hip in neutral rotation and 45 ° of flexion. Top leg then internally rotated. Knee height remains the same throughout the entire movement. **Clam Shell 4** = Same as 3 except the top leg is in extension **Clam shell PNHIP0** = pelvis neutral, hip in 0° of flexion **Clam shell PNHIP30** = pelvis neutral, hip in 30° of flexion **Clam shell PNHIP60** = pelvis neutral, hip in 60° of flexion **Clam shell PRHIP0** = pelvis reclined, hip in 0° of flexion **Clam shell PRHIP30** = pelvis reclined, hip in 30° of flexion **Clam shell PRHIP60** = pelvis reclined, hip in 60° of flexion

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