INCREMENTO DE LA ACTIVACIÓN MUSCULAR DEL GLUTEO MEDIO A TRAVÉS DEL USO DE UN NUEVO APARATO DE ENTRENAMIENTO

INCREASING ACTIVATION OF THE GLUTEUS MEDIUS USING A NEW TRAINING DEVICE


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RESUMEN
Objetivos: El glúteo medio (GM) es un potente abductor y rotador medial del muslo, y juega un importante papel en la estabilización de la pelvis y en el control de las rodillas durante la actividad física. La falta de potencia en el GM puede tener efectos adversos en el rendimiento, así como incrementar el riesgo de lesiones en los miembros inferiores. El objetivo de este estudio fue validar un nuevo aparato de entrenamiento comparando la activación del GM durante la ejecución de un squat con y sin el citado aparato. Material y métodos: 32 mujeres atletas (edad media 20 ± 3) llevaron a cabo squats solo con el propio peso corporal sobre el aparato y fuera de él, realizándose mediciones electromiográficas bilaterales en el GM. Resultados: Todos los sujetos participantes fueron capaces de realizar el squat y de activar el GM. Dicha activación aumentó significativamente con el uso del nuevo aparato respecto a su realización en el suelo (Z=-4.9, P<0.001). Los test de correlación entre una secuencia completa de 3 squats y una repetición seleccionada, reveló que la activación se sostenía a lo largo de todo el ejercicio (GM derecho: r_s=0.93, P<0.001, GM izquierdo: r_p=0.92, P<0.001). No se observaron diferencias de activación entre el GM derecho y el izquierdo sobre el aparato. Conclusiones: El aparato de entrenamiento que hemos desarrollado incrementa la actividad muscular del GM durante los squats. Además, los resultados mostraron que los saltos sobre el aparato activan los lados derecho e izquierdo del cuerpo por igual, y que el GM se activó durante todo el ejercicio de flexión de cadera. El nuevo aparato de entrenamiento se puede usar en programas de entrenamiento para mejorar la estabilidad de la pelvis y de las extremidades inferiores durante el ejercicio dinámico.

Palabras clave: Mujeres atletas, electromiografía, rehabilitación, pelvis, extremidades inferiores, ejercicio dinámico.

ABSTRACT
Objective: The gluteus medius (GM) is a strong abductor and medial rotator of the thigh, and plays an important role in stabilizing the pelvis and controlling the knees during athletic activities. Weakness in the GM can have adverse effects on performance and increase the risk of lower extremity injuries. The aim of this study was to validate a new training device by comparing the activation of the GM when performing a squat with and without the device. Methods: Thirty-two female athletes (mean age 20 ± 3) performed body weight squats on and off the device, while surface electromyography was recorded bilaterally on the GM. Results: All test subjects were able to perform the squat and to activate the GM. The activation of the GM was significantly higher when using the new device than when performing squats on the floor (Z=-4.9, P<0.001). Correlation tests between a complete sequence of three squats and one selected repetition revealed that activation was consistent throughout the exercise (right GM: r_s=0.93, P<0.001, left GM: r_p=0.92, P<0.001). No differences in activation were found between the right and left GM when squatting on the device. Conclusion: The newly developed training device increases muscle activity in the GM during squats. Moreover, the results showed that squatting on the device activates the left and right side of the body equally, and that the GM was activated during the whole hip flexion exercise. This information and the new training device can be used in training programs to improve stabilization of the pelvis and lower extremities during dynamic exercises.

Keywords: Female athletes, electromyography, rehabilitation, pelvis, lower extremity, dynamic exercises.
INTRODUCTION

The gluteus medius (GM) is a strong abductor and medial rotator of the thigh, and plays an important role in stabilizing the pelvis and controlling the knees during athletic activities (Gottschalk, Kourosh, & Leveau, 1989; Krause et al., 2009). As a stabilizer of the pelvis in the coronal plane, the GM helps create a stable base for force development of the mobilizing muscles by exerting a continuous hip abductor moment (Blazevich, 2000; Fredericsson & Guillet, 2000). During movements in all three planes, the GM is important in stabilizing the pelvis and the knee so that the force can be directed upwards, and it also plays a role in controlling the axial rotation of the pelvis in throwing and punching motions (McGill, Karpowicz, & Fenwick, 2009; O'Sullivan, Smith, & Sainsbury, 2010; Oliver & Keeley, 2010).

Weakness of the GM will cause the axially loaded leg to adduct, the femur to rotate internally and the tibia to rotate externally, placing the knee in a valgus position (Ireland, 1999; Krause, et al., 2009; Presswood, Cronin, Keogh, & Whatman, 2008). A weak GM may be the result of inactivity, injury or inappropriate training. Furthermore, body structure influences the ability of the GM to function. For example, females have been shown to have decreased strength in the hip abductor muscles, and also an increased valgus position in jump landings (Jacobs, Uhl, Mattacola, Shapiro, & Rayens, 2007). Studies suggest that this effect can be related to the wider hips that females have, which increases the femoral lever arm acting on the GM and the pelvic width to femoral length ratio (Pantano, White, Gilchrist, & Leddy, 2005; Preininger et al., 2011).

Exercises previously used to strengthen the GM in interventions are variations of hip abduction exercises, balance exercises on devices like wobble boards or BOSU® balls, single-leg balance exercises and squats (2009; 2004; Presswood, et al., 2008). However, the specificity of these exercises for functional kinematic patterns is the subject of debate. Although hip abduction exercises may strengthen the GM, they only do so in one fixed degree of hip flexion (2008). Balance devices like wobble boards and BOSU balls may help to increase balance, but may not be effective in strengthening the GM (2009; 2004). When the activity of the GM was compared during single-limb stance and single-limb squats, performed on the floor and on an unstable surface, no significant difference was found (Krause, et al., 2009). Neither was any medial-lateral stability effect achieved when balance exercises using balls were conducted on 41 female school athletes (Paterno, et al., 2004). However, another study has shown that single-leg exercises increase the activation of the GM, but the authors emphasize that these exercises require good strength, balance and coordination to be performed correctly (Zeller, McCrory, Kibler, & Uhl, 2003). One-legged pressing against a wall seem to be an efficient exercise to activate the GM compared to squat and pelvic drop (O'Sullivan, et al., 2010).
The functional anatomy of the GM reveals that the muscle is divided into three parts, with three distinct muscle fiber directions, and that different parts of the muscle are primarily activated depending on the degree of hip flexion (Delp, Hess, Hungerford, & Jones, 1999; Dostal, Soderberg, & Andrews, 1986). According to the principles of training specificity, a muscle should be trained in a way that is specific to how it will function (Behm & Anderson, 2006). The anterior part of the GM is in an advantageous position to abduct the hip and stabilize the pelvis laterally at zero degrees of hip flexion. With increasing hip flexion, the moment arm vector for abduction decreases in the anterior part of the GM while it increases in the intermediate part, making this part the primary abductor. At angles beyond 40 degrees of hip flexion the GM no longer abducts the hip (Dostal, et al., 1986). The GM also rotates the femur externally and internally and, as with abduction of the hip, the function changes depending on the hip flexion angle. At zero degrees of flexion the most anterior part of the muscle works as an internal rotator, while the rest of the muscle functions as an external rotator. As the hip flexion angle increases the external rotational moment arms decrease in the rest of the muscle (Delp, et al., 1999). During functional activities, the GM acts primarily to provide isometric stabilization, implying that it should be trained isometrically in dynamic exercises. Hence, using training methods that are not specific to the function of the GM may not provide the desired effects on kinematic patterns in functional tasks, indicating that other training methods that specifically activate the GM are required.

A new training device was developed to enable increased muscle activity in the GM during dynamic strength exercises. The aim of this study was to test the activation of the GM during a squat exercise with and without the device. The muscle activation was measured with sEMG. The hypothesis was that performing a squat with the new training device would increase the amplitude of GM activation throughout the full range of movement, and increase the consistency of muscle activation throughout the squat.

### METHODS

#### Subjects

The study group consisted of 32 female athletes (mean age, 20 ± 3 years; height, 167 ± 7 cm; weight, 63 ± 9 kg), at amateur level (15 volleyball players, 5 soccer players, 3 equestrians, 3 golfers, 3 table tennis players and 3 dancers). Subjects with a recent or present knee injury were excluded from the study. All procedures complied with the Declaration of Helsinki.

#### Design

An intra-subject design was used to compare squats performed with the new training device with squats performed on the floor. All trials were performed on one occasion in April 2011, including a maximal voluntary isometric contraction (MVIC), a body weight squat on the floor, and a body weight squat using the new training device.

#### Training device

A new training device was developed to offer rotational resistance during a complete squatting movement, in order to activate the GM throughout the exercise (Figure 1). The new device for the left and right foot respectively consists of two plates that rotate in relation to each other around a vertical axis. The diameter of the plates is 0.32 m and the height is 0.065 m. The subject stands with one foot on each device, with the lateral side of the feet against the foot stops and the heels as far back as possible while still on the device. Pressing the feet apart, out against the foot stops, causes the top plates to rotate and the lower extremities to rotate internally. The outward force should be applied continuously throughout the squatting movement. To enforce this, a feedback mechanism was installed in the device that alerted the subject when the plates rotated back towards the initial position.

![Figure 1. New training device](image1.jpg)
Exercises
The subjects were instructed how to perform the exercises, and given a few minutes to practice (Krause, et al., 2009). Body weight squats on the floor were performed first, to 90 degrees of knee flexion, determined using a set square. Each participant performed three squats (Andersen et al., 2006). The pace of the squats was as follows: one second at the top (standing up), two seconds of downward motion (eccentrically), zero seconds at the bottom and one second of upward motion (concentrically), after which a new squat began. A metronome was used to help subjects maintain the correct pace (Farina, Fosci, & Merletti, 2002). After this, squats were performed on the new training device (Figure 2). These squats were executed in exactly the same way as the previous ones, except that the subjects were instructed to push outwards against the resistance of the plates during the whole squat. Two cues were used to enforce this: “push the plates apart” and “try to perform the splits”. Subjects were also told not to let their feet rotate externally, back to the original position. If this occurred, the feedback mechanism would give a signal and the subjects were told to respond to this by applying more force. During all the squatting exercises, both on and off the device, the subjects were encouraged to maintain a good squat position by aligning their knees with their feet.

Figure 2. Squat on the new training device

The MVIC for the GM was performed to allow the sEMG data to be normalized. This was performed with the subject lying in a side prone position on a table (Figure 3), as described by Kendall et al. (1993). The hip was abducted 30 degrees before the MVIC was performed against the hand of one of the researchers. This contraction was then held for 6 seconds (Ebersole et al., 1998). Three trials were performed on each side, with adequate rest between the series (Krause, et al., 2009). The subjects were verbally encouraged to perform maximally during all trials.

Figure 3. MVIC

Measurement setup
The electromyographic activity of the GM was measured bilaterally during the three exercises (Figure 4). The skin was cleaned with ethanol to minimize impedance before two disposable, pre-filled Ag/AgCl Ambu blue sensor surface electrodes (Ambu A/S. Ballerup, Denmark) were attached over the muscle belly of the GM, aligned with the direction of the fibers, half-way between the trochanter major and the crista iliaca, with a distance of 20 mm between the electrodes. A third reference electrode was attached on the iliac crest, perpendicular to the two other electrodes (Hermie, Hermens, Freriks, Disselhorst-Klug, & Rau, 2000). The ME6000 8-channel Biomonitor system (Mega Electronics Ltd., Kuopio, Finland) was used for sEMG measurements. Data were collected at a sampling frequency of 1000 Hz. Raw EMG-signals were full wave rectified and RMS averaged. For all subjects the Gluteus medius activity during three complete sequences of squats (five repetitions) as well as the second repetition in each sequence was normalized and expressed as a percentage of the
MVIC’s. The mean values of activity (both for complete sequences and single repetitions) over the three trials were then calculated to be used in the statistical analysis.

Statistical analysis

Raw EMG data were processed with Megawin software (Mega Electronics Ltd., Kuopio, Finland). The data were corrected to the root mean square average. Values were obtained from the third MVIC trial of each subject. Values from the complete sequences of squats, on the device and without it, and the second squat of each sequence were normalized and expressed as a percentage of the MVIC, enabling inter-muscular comparisons to be made (Krause, et al., 2009). A sample size of 32 subjects was deemed sufficient based on pre-tests that allowed estimation of an effect size above 0.8 and α error was set to 0.05 (two tails).

Distributions of continuous variables are presented as the mean, standard deviation and range. For group comparisons of independent samples the Wilcoxon signed-rank test was used. Spearman’s rank (r_s) correlation test was applied to assess correlations between complete sequences of squats and single squats in the right GM, since these results were non-parametric. A p-value of less than 0.05 was considered to be significant. SPSS version 18.0 for Windows XP was used in the statistical analysis.

RESULTS

All subjects exhibited increased sEMG activation when performing squats on the device. Table 1 presents the mean values (± SD) and ranges of activation during complete sequences of squats and the second squat only, on and off the device. Performing squats using this new device increased the muscle activity by 365 %.

No significant differences in activation were seen between the right and left GM during squats on the device, during complete sequences (Z=-1.6, p=0.12, r=0.3) or between the single (second) squat (Z=-1.9, p=0.06, r=0.3).

The test of consistency of muscle activation throughout the squats showed that there was no difference between the complete sequences, right and left GM, and the single (second) squat, right and left GM, (Z=-4.9, p<0.001, r=0.9). Furthermore, significant correlations were found between the single squat and full sequences of squats for the right and left side GM (r_s=0.93, p<0.001). Results from
Table 1. Results of sEMG (% MVIC) activation in the GM during squats on and off the device (N=32). Values of Z from the Wilcoxon signed-rank test and significant differences between squats on and off the device are given.

<table>
<thead>
<tr>
<th>Squats</th>
<th>On device Mean value ± SD (range)</th>
<th>Off device Mean value ± SD (range)</th>
<th>Z-value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Complete sequences</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right GM</td>
<td>39.1 ± 13.4 (22-82)</td>
<td>10.8 ± 3.8 (5-21)</td>
<td>-4.9</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Left GM</td>
<td>42.6 ± 14.5 (18-74)</td>
<td>11.5 ± 4.3 (5-21)</td>
<td>-4.9</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Second squat</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right GM</td>
<td>39.9 ± 14.9 (20-94)</td>
<td>10.8 ± 4.1 (5-22)</td>
<td>-4.9</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Left GM</td>
<td>44.5 ± 17.9 (17-84)</td>
<td>11.8 ± 5.2 (5-26)</td>
<td>-4.9</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

The squat is a fundamental movement pattern which, in one form or another, is included in most sports and many daily activities. Squats also challenge the stabilizing functions of the GM over a range of hip flexion, such as in the functional activities running, walking and jumping (Abelbeck, 2002; Kritz, Cronin, & Hume, 2009). Traditional exercises to strengthen the hip abductor muscles do not allow isometric contraction of the GM simultaneously as a functional movement, and this may explain why increased hip abductor strength as a result of hip abductor exercises has not led to improvement in the kinematic pattern during functional activities (Herman, et al., 2008). We found that squatting with the new device resulted in significantly higher GM activation than regular body weight squats on the floor, indicating that the former is a more challenging exercise for the GM. Previous studies focusing on GM activation during squatting exercises have found that unilateral exercises produce higher EMG values than bilateral exercises, with greater activation the smaller the support surface. Boudreau et al. 2009 compared activity in the GM during single-leg squats, lunges and a step-up-and-over exercise (2009). Muscle activation was greatest during the single-leg squat. However, single-leg squats may not be an advisable exercise for all female athletes, according to the results of a study showing that women had difficulties performing the exercise correctly, also showing lower EMG activity in the GM than in men (2003). We, therefore, propose a new method of increasing the GM activity in squat exercises based on a two-legged squat, requiring less balance and coordination skills to perform the exercise. The new device offers a means of exercise if the intention is to provide a greater challenge to the GM than other squatting exercises, or if the individual has trouble performing unilateral leg exercises due to injury or other weaknesses. The resistance in the device can be adjusted, allowing progressive resistance exercise. It may also be used to progressively strengthen the GM specific to functional activities in order to decrease lower extremity movement patterns associated with poor performance and risk of injury. However, this remains to be explored in future research.

The high correlation found between one squat in a sequence and complete sequences of squats indicates that GM activation is consistent throughout the exercise, hence activating the muscle isometrically during the movement. Minimum values reveal that activation was consistent throughout each repetition, which is important because different parts of the GM become activated depending on the hip flexion angle. No significant differences in activation were found between right and left GM, indicating that the load was bilaterally equal. However, some individual subjects exhibited considerable discrepancies. A plausible explanation of this might be that these subjects had strength imbalances between the right and left side of the GM. Therefore, another possible use of the device, in conjunction with a dynamometer, could be to measure the asymmetry of strength to reveal imbalances in the GM during a weight-bearing activity.

Using sEMG to measure muscle activity requires some understanding of the method, including its possibilities and limitations. The sEMG registers the total impulse, i.e. the sum of all action potentials over the measured area, yielding a higher result with increased voltage(Roeleveld & Stegeman, 2002).
However, despite a relationship between force and sEMG values, force cannot be estimated through sEMG alone. Artifacts, such as increased impedance in the tissue, crosstalk, and differences in electrode position may influence the recordings. Additionally, the relationship between force and sEMG amplitude may vary between muscles, due to differences in recruitment properties and firing rates (Cram & Kasman, 1998). Because of this muscular and individual variability, sEMG data from different subjects or different muscles in a single subject cannot be compared without first being normalized, i.e. expressed as a percentage of the MVIC. Another factor that may influence the sEMG value is the speed of muscle contraction, as higher speed of contraction yields greater sEMG values (Krause, et al., 2009). This influence was minimized by having the subjects perform the exercises at a pre-determined pace.

A limitation of this study is that all subjects performed squats on the device with the same amount of resistance, regardless of individual strength. This may have affected the mean activation and may be partly responsible for the relatively high standard deviations between subjects. Furthermore, only female subjects participated in this study, and it is not certain that male subjects would have exhibited similar result. However, the strong statistical differences showed in this study suggest that also other participants might show the same pattern.

The results of this study show that the new training device increases the activation of the GM during squats. Moreover, the results showed that squatting on the device activates the left and right side of the body equally, and that the GM was activated during the whole hip flexion exercise. This information can be used in training programs to create dynamic exercises to improve stabilization of the pelvis and lower extremities.

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