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# Performing Smart Squats: Measurement of lower train impacts upon performing squats amongst amateurs and experienced individuals

Sistematización de experiencias prácticas de investigación

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# RESUMEN

En la industria del deporte hay varios problemas relacionados con el servicio al cliente, en este caso específico, las lesiones del cliente se convierten en una fuente importante de quejas y descontinuación del servicio. En este estudio, analizamos la comparación entre los participantes amateurs y experimentados, y también la diferencia entre hombres y mujeres de ciertos grupos al realizar sentadillas estáticas y dinámicas. El propósito de este análisis es determinar si existe una diferencia significativa entre los grupos mencionados anteriormente, para poder proponer conclusiones o soluciones correspondientes a los resultados; específicamente en dos músculos, recto femoral y vasto medial oblicuo. La electromiografía (EMG) se utiliza como la herramienta principal para el estudio, junto con un modelo estadístico mixto, el análisis de la media cuadrática y el análisis de amplitud. Los individuos amateurs (N = 12) y experimentados (N = 12) completaron tanto las sentadillas dinámicas como las estáticas (10 kg) a lo largo de intervalos de 90 y 20 segundos respectivamente. La activación muscular del recto femoral y el vasto medial oblicuo se midió en un solo día por sujeto; donde las diferencias resultantes en la actividad muscular se observaron en cambio porcentual. Los resultados muestran que existe una diferencia significativa a favor de las mujeres experimentadas entre un grupo de solo mujeres en el recto femoral al realizar sentadillas dinámicas. También hay una diferencia significativa a favor de las mujeres entre un grupo de participantes experimentados únicamente en el recto femoral al realizar sentadillas dinámicas. No se encontraron diferencias significativas para las sentadillas estáticas y el vasto medial. Las sentadillas dinámicas permiten tener una mayor diferencia en la activación muscular del recto femoral. Las participantes femeninas, que están debidamente capacitadas, experimentarán una mayor activación muscular del recto femoral al realizar sentadillas dinámicas. Además, dentro de la población experimentada de clases de aeróbicos, las mujeres experimentarán una mayor activación muscular del recto femoral a lo largo del tiempo durante el ejercicio. Los resultados de este estudio podrían mejorar y beneficiar la instrucción profesional durante una clase de aeróbicos para adaptarse adecuadamente al nivel atlético y al género del individuo.

# ABSTRACT

In the sports industry there are several problems related to customer service, in this specific case, client injuries become a major source of complaints and discontinue of service. In this study, we analyze the comparison between amateur and experienced participants mainly and also the difference between men and females of certain groups when performing static and dynamic squats. The purpose of this analysis is to determine if there is a significant difference between the previously mentioned groups, in order to be able to propose conclusions or solutions corresponding to the results; specifically, in two muscles, rectus femoris and vastus medialis. Electromyography (EMG) is used as the main tool for the study, along with a mixed statistical model, root mean square analysis and amplitude analysis. Amateur (N = 15) and experienced (N = 15) individuals completed both dynamic and static (10kg) back-squats through the duration of 90 and 20 second intervals respectively. Muscle activation of the rectus femoris and the vastus medialis oblique where measured in one single day per subject; where resulting differences in muscle activity where viewed in percentage change. The results show that there is a significant difference in favor of experienced females among a group of only females in the rectus femoris when performing dynamic squats. There is also a significant difference in favor of females among a group of only experienced participants in the rectus femoris when performing dynamic squats. No significant difference was found for the static squats and the vastus medialis. The dynamic squats allow for a greater difference in muscle activation of the rectus femoris. Female participants, who are properly trained, will experience a greater muscle activation of the rectus femoris while performing dynamic squats. Furthermore, within the experienced population of aerobics classes, females will experience a greater muscle activation of the rectus femoris over time during exercise. The results of this study could improve and benefit professional instruction during aerobics classes in order to properly adapt to the athletic level and gender of the individual.

## Contents

# Performing Smart Squats: Measurement of lower train impacts upon performing squats amongst amateurs and experienced individuals

## Introduction

Back-squats are commonly used in a wide variety of environments, ranging from clinical rehabilitation, group fitness programs, to strength and conditioning programs; not leaving aside everyday gym environments. Additionally, daily movements also require the use of the squat, turning it into a matter of healthy lifestyle as well. Over the years, squats have been used as a hip and knee exercise to strengthen the thigh musculature (Caterisano, 2002); but when this popular technique is not properly executed, the knee could be compromised, as the lack of experience could lead to a deviation over the knee creating a bad impact in both the knee and a wrong activation of the Vastus Medialis Oblique (VMO) and the Rectus Femoris (RF) (Nishiwaki, 2006).

It is known that performing a poor squat could bring negative impacts on the knee, such as patellofemoral joint reaction force (PFFS) (Cotter, 2013). There could be harmful forces created by sloppy squat performance which may lead to patellofemoral pain syndrome (Cotter, 2013). In addition, studies report that the squat is safe for the ligaments when executed correctly (Sampaio, 2011). Nevertheless, executing squats successfully brings positive impacts, and the ability to detect and correct wrong movements will undoubtedly prolong the knee articulations' life span (Neitzel, 2000). EMG techniques to measure muscle activation in squats are viable, given that the thigh muscle will deliver electronic measurements due to its big size, giving a clear insight of the activation quantity of the muscles beings studied (Caterisano, 2002). The greatest part of the muscle activation comes from the quadriceps itself (Nishiwaki, 2006). There are forces in the knees (Patellofemoral, Tibiofemoral, and Tibiofemoral joints) which result in peak values near maximum knee flexion (Barbosa, 2017).

EMG measuring technique has been proven accurate and reliable, and since the release of the surface EMG it has become less invasive, allowing more studies to take place (Del Monte, 2014). Additionally, for a correct measurement, placing EMG sensors on only the dominant limb is shown to be enough, assuming symmetric posture (Del Monte, 2014); that way, when disposing of few sensors, more measurements can be executed. To determine the activation of the muscle during the squat performance, EMG was ultimately used as a measurement technique for this study.

The Vastus Medialis Oblique (VMO) muscle activity gives a potent insight of the stress focused on the Patellofemoral ligament; thus EMG readings of this muscle are an indicator for the impact on the lower limbs (Signorile, 1994). It is generally suggested that the greater the force exerted on the knee, the greater the muscle development becomes (Hyong, 2013). Applying a greater force could magnify the risk of injury, making squats a double-sided sword (Escamilla, 2001).

In many group fitness classes, such as aerobics, squatting over 100 times during a one-hour class is common (Crespo, M. (2018, April 6) personal interview). The aim of the present study was to measure and compare the muscular activation of the VMO and the RF between amateur and experienced participants within men and females when performing static and dynamic squats during a controlled aerobics workout.

## Methods

### *Participants*

Participants included 30 healthy individuals, divided into 15 amateur and 15 advanced participants. All of whom were attending the university group fitness classes guided by the same instructor. Additionally, participants were free of any injury. Group members were selected with two main criteria: amount of time dedicated for sports activities during the week and the binary decision whether the knee surpasses the toes or not when performing an in-class squat. Participants were informed of risks and benefits prior to the measurement procedure. Men participants did not belong to the aerobics class, they were rather taken from other sports classes. Table 1 shows descriptive characteristics of said participants.

**Table 1** Descriptive characteristics of participants (n=30)

| Patricipants | *Age (years)* | *Weight (lb)* | *Height (cm)* |
|---|---|---|---|
| Amateur females | 19.5 (1.47) | 123.80 (9.54) | 158.59 (3.97) |
| Experienced females | 25.57 (1.21) | 115.65 (7.37) | 160.33 (16.20) |
| Experienced men | 23.00 (1.47) | 168.12 (17.91) | 178.70 (8.90) |

### *Apparatus*

Delsys Trigno surface bipolar EMG was used with a sampling frequency of 31.57 Hz; each sensor being non-disposable, equipped with parallel bar electrode technology. Sensor signal filtering is a maximally flat Butterworth (1.5 ms), preserving signal amplitude and phase linearity. Bandwidth of the EMG signal is specified with 20±5 Hz, >40 dB/dec and 450±50 Hz, >80 dB/dec. The sensor requires only to have direct contact with clean skin for it to transmit clear EMG signals to its base receptor; all done completely wireless.

### *Procedures*

Participants were required to attend one session only, lasting roughly 40 minutes for each participant. The subject was asked to show up with comfortable, loose shorts and a shirt. Immediately, participants were handed a questionnaire asking for their age, weight and height, for them to answer and sign. After the paperwork, participants were asked to perform a warm-up for a duration of five minutes. Then, participants were

asked to sit down so the quadriceps (Vastus Medialis Oblique and Rectus Femoris) could be cleansed with makeup cotton dipped in alcohol. Afterwards, one EMG sensor was placed exactly on top of each muscle in the exact direction of the muscle fiber; the dominant leg was used for measurements, defined by the participant as its strong leg, resulting in the right leg for all participants. Sensors were fixed in place using two-sided, Delsys disposable adhesive sheets plus a strip of sticking plaster for extra safety.

Participants proceeded to stand on the taped area of the squatting mat, and were asked to follow the instructions of a 9-minute-long videotape prerecorded to show accurate instructions from their current fitness instructor. The video was segmented into a proper warm-up, a corresponding MVC normalization using a 10kg kettle bell, a non-stop squatting session with 5kg, a proper rest, and finally a jumping squat session. Upon finalizing the measurement, the subject was encouraged to perform quadriceps stretches and given a hydrating electrolyte drink.

Two videos were made, in which a fitness instructor performed the described routine while giving clear instructions, but the order of the squatting activity was inverted for each video. One video started with continuous squats and the other with dynamic squats. Participants were asked to follow the fitness instructor commands in real time. Participants were randomized upon entry to determine which video would be used during their measurement.

*EMG Data Processing*

Maximum Voluntary Contraction (MVC) normalization was used for this study. This method utilizes a maximum root mean square (RMS) value from recordings to normalized subsequent data series (Delsys, N.D.). The final result is expressed as a percentage of the MVC; proving useful when wanting to establish a common ground to compare the data obtained between different participants (Delsys, N.D.). Normalization occurred by using 10kg weight on each subject was well as a well-defined taped area where the subject stands during exercise. The most common method of normalization in EMG signals is the maximal voluntary isometric contraction which is a reference test usually done by a manual muscle exercise.

Once the raw data was obtained signals were then treated with an amplitude measure and then full wave was rectified and smoothed using a root-mean-square (RMS) filter with a moving window of 250ms (Allen et al. 2013). Muscle activity was calculated by subtracting the average peak amplitude of 5 repetitions for the simple squats and 3 for the dynamic repetitions then a pause of 5 squats for the continuous and 2 squats for the dynamic until the data set is done.

*Statistical analyses*

A mixed model analysis was used to compare the activation of both muscles, variables being: time elapsed and level of expertise (experienced and amateur individuals). The ultimate criterion used was the p value combined with the established alpha of 0.05, therefore proving statistical difference or not. Two different models were used with two dependent variables: EMG (RMS) rectus femoris and EMG (RMS) vastus medialis. The first model consisted on a fixed factor of only females and variable factors of time elapsed during exercise, and finally experience. The second model consisted on a fixed factor of only experienced individuals and variable factors of time elapsed and gender. Six outliers were removed in total.

## Results

Statistical results of muscle activity for the rectus femoris and vastus medialis within all groups are presented in the tables bellow (Table 2–7). Muscle activity of the rectus femoris for experienced individuals within a female-only group performing dynamic squats was statistically greater, $p < .01$ (Table 3). Within experienced individuals only, females showed a significantly greater rectus femoris muscle activity over time during exercise, $p = .028$ (Table 5). However, no significant differences were found for the vastus medialis (Table 2 and 4) and the simple squats (Table 2-5). Graph 1 represents the significance of the rectus femoris in dynamic squats of the female only group; graph 2 represents the significance of the rectus femoris in dynamic squats of the experienced only group.

**Table 2** Effects of female only group – vastus medialis

| Effect | Simple | | | | Dynamic | | | |
|---|---|---|---|---|---|---|---|---|
| | *DF Num* | *Den DF* | *F value* | *P value* | *DF Num* | *Den DF* | *F value* | *P value* |
| Time | 3 | 44 | 0.31 | 0.8150 | 1 | 14 | 2.07 | 1.1726 |
| Experience | 1 | 44 | 1.70 | 0.1990 | 1 | 14 | 0.07 | 0.7913 |
| Experience*time | 3 | 44 | 0.61 | 0.6100 | 1 | 14 | 2.30 | 0.1520 |

**Table 3** Effects of female only group– rectus femoris

| Effect | Simple | | | | Dynamic | | | |
|---|---|---|---|---|---|---|---|---|
| | *DF Num* | *Den DF* | *F value* | *P value* | *DF Num* | *Den DF* | *F value* | *P value* |
| Time | 3 | 44 | 1.13 | 0.3454 | 1 | 14 | 12.35 | **0.0034*** |
| Experience | 1 | 44 | 2.82 | 0.1002 | 1 | 14 | 2.44 | 0.1405 |
| Experience*time | 3 | 44 | 1.24 | 0.3071 | 1 | 14 | 13.71 | **0.0024*** |

**Significant group difference; p < .05*

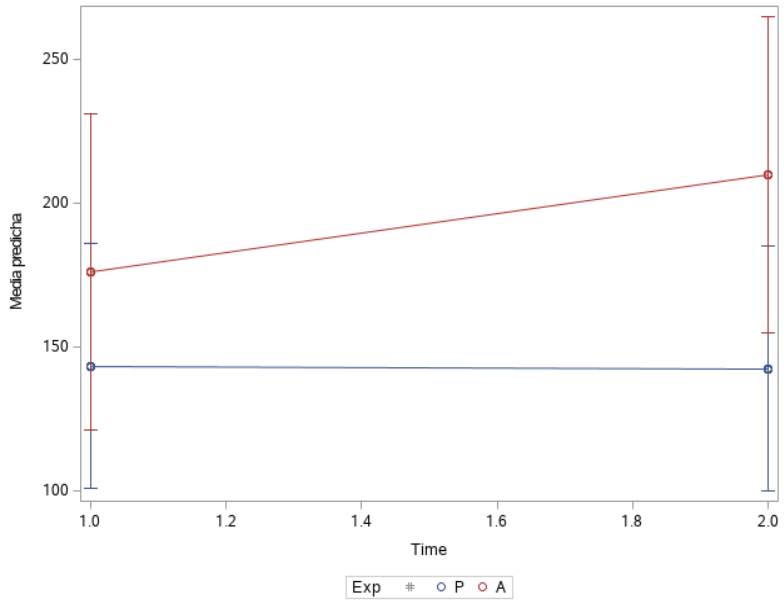
**Table 4** Effects of experienced only group – vastus medialis

| Effect | Simple | | | | Dynamic | | | |
|---|---|---|---|---|---|---|---|---|
| | *DF Num* | *Den DF* | *F value* | *P value* | *DF Num* | *Den DF* | *F value* | *P value* |
| Time | 3 | 27 | 0.25 | 0.8587 | 1 | 9 | 0.00 | 0.9774 |
| Experience | 1 | 27 | 1.43 | 0.2427 | 1 | 9 | 0.16 | 0.7021 |
| Experience*time | 3 | 27 | 0.34 | 0.7962 | 1 | 9 | 0.01 | 0.9369 |

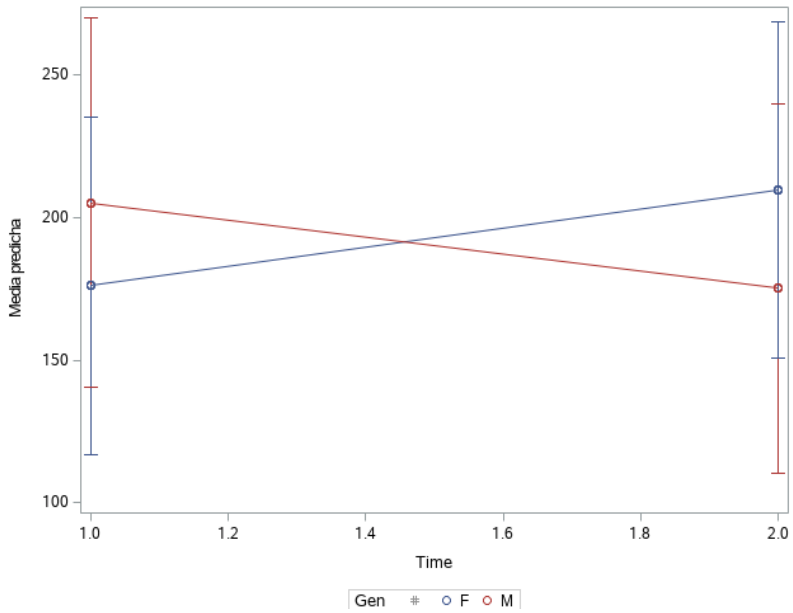
**Table 5** Effects of experienced only group – rectus femoris

| Effect | Simple | | | | Dynamic | | | |
|---|---|---|---|---|---|---|---|---|
| | *DF Num* | *Den DF* | *F value* | *P value* | *DF Num* | *Den DF* | *F value* | *P value* |
| Time | 3 | 27 | 1.66 | 0.1986 | 1 | 9 | 0.02 | 0.8901 |
| Experience | 1 | 27 | 0.86 | 0.3624 | 1 | 9 | 0.01 | 0.9421 |
| Experience*time | 3 | 27 | 0.49 | 0.9620 | 1 | 9 | 6.88 | **0.0277*** |

(*)*Significant group difference; p < .05*




**Graph 1** Interaction graph for female only group – rectus femoris. P = amateurs and A = experienced




**Graph 2** Interaction graph for experienced only group – rectus femoris. F = female and M = male.

## Discussion

Difference of muscle activity of the rectus femoris and the vastus medialis during simple and dynamic squats was assessed between experienced and amateur groups of females and men in the present study.

*Amateur and experienced females*

The present study showed a significant difference of muscle activation between experience and amateur females during dynamic squats. However, this difference was not observed in the vastus medialis or during static squats. Perhaps, maintaining posture during the static squats is easier than for dynamic squats. It is known that that the muscle activity of lower trunk muscles during squat lifting is influenced by weight carried (Vahdat et al; 2016). This means that the study might need extra weight that will challenge participants to truly recruit their authentic posture. Also, it has been shown that there are gender differences regarding neuromuscular characteristics of the lower extremity in response to perturbation. (Medina, Valovich, Howellc, & Kingmab; 2008) This opens the discussion about how gender physiology and anatomic characteristics could affect muscle activity during squats.

Fitness level may influence muscle activation and strategies when performing squats or other movements during group fitness classes (Medina, Valovich, Howellc, & Kingmab; 2008) Thus, the difference in terms of muscle activity of amateurs and experienced fitness group classes participants could contribute to a better design of the class and improved supervision of correctly executed exercises. This may prevent potential injuries particularly in amateur participants.

*Experienced females and males*

Our results showed a significant difference between experience females and males during the performance of dynamic squats in the rectus femoris muscle. It is thought that men fell below females in muscle activity in time elapsed during exercise because females were frequent aerobics classes´ participants, in which students are taught to follow the instructor as accurate as possible and to maintain form and posture over time. It has also been shown that females and males have different neuromuscular strategies that control the knee joint during dynamic squat landings, supporting the results of this study by knowing the knee joint directly affects the muscle activity of the rectus femoris (Gehring, Melnyk, & Gollhofer; 2009). The significant difference between females and males highlight the importance of considering gender influence when evaluating this type of activities.

Furthermore, possible limitations to this study consist of including only two muscles and leaving aside other involved ones during dynamic and static squats. Also, the lack of male participants in group fitness classes forced us to seek male athlete participants of other sport classes, which may not be familiar to following an aerobics instructor. Further studies may consider performing the measurements on-site during the real aerobics class.

## Conclusions

Present findings point out mainly that the rectus femoris is an important source of difference in the percentage of muscle activity when differentiating groups while performing dynamic squats. When analyzing females only, the experimented group of this population showed a greater muscle activity of the rectus femoris over time during dynamic squats. However, for the vastus medialis and the static squats, no statistical difference was observed; enabling the conclusion that the rectus femoris has a greater activation than the vastus medialis, making it great to be a measurable indicator when evaluating dynamic squats. Furthermore, when analyzing experienced individuals, females showed and maintained a greater muscle activity of the rectus femoris over time, while men, on the contrary, demonstrated a decrease in muscle activity of the rectus femoris over time. For this group also, static squats and the vastus medialis showed no statistical difference when developing the exercise, strengthening the conclusion stated above. Also, the lack of difference in the static squats may be due to the fact that maintaining posture in static squats is considerably easier that in dynamic squats; regarding the vastus medialis, it is considerably less affected when performing dynamic squats.

## References

Barbosa, A. C., Martins, F. M., Silva, A. F., Coelho, A. C., Intelangelo, L., & Vieira, E. R. (2017). Activity of Lower Limb Muscles During Squat With and Without Abdominal Drawing-in and Pilates Breathing. Journal of Strength and Conditioning Research, 31(11), 3018–3023. https://doi.org/10.1519/JSC.0000000000001877

Caterisano, A., Moss, R. F., Pellinger, T. K., Woodruff, K., Lewis, V. C., Booth, W., & Khadra, T. (2002). The effect of back squat depth on the EMG activity of 4 superficial hip and thigh muscles. Journal of Strength and Conditioning Research, 16(3), 428–432. https://doi.org/10.1519/1533-4287(2002)016<0428:TEOBSD>2.0.CO;2

Cotter, J. A., Chaudhari, A. M., Jamison, S. T., & Devor, S. T. (2013). Knee Joint Kinetics in Relation to Commonly Prescribed Squat Loads and Depths. *Journal of Strength and Conditioning Research / National Strength & Conditioning Association*, *27*(7), 1765–1774. http://doi.org/10.1519/JSC.0b013e3182773319

Chelladurai, P., & Carron, A. (2018). *Athletic Maturity and Preferred Leadership | Journal of Sport and Exercise Psychology*. *Journals.humankinetics.com*. Retrieved 9 April 2018, from https://journals.humankinetics.com/doi/pdf/10.1123/jsp.5.4.371

Crespo, M. (2018, March 20). Personal Interview.

Del Monte, M. J., Opar, D. A., Timmins, R. G., Ross, J., Keogh, J. W. L., & Lorenzen, C. (2014). Hamstring myoelectrical activity during three different kettlebell swing exercises. The Journal of Strength & Conditioning Research, Publish Ah. Retrieved from Journal of Strength and Conditioning Research

Escamilla, R. F., Fleisig, G. S., Zheng, N., Lander, J. E., Barrentine, S. W., Andrews, J. R., … Moorman, C. T. (2001). Effects of technique variations on knee biomechanics during the squat and leg press. Medicine and Science in Sports and Exercise, 33(9), 1552–1566. https://doi.org/10.1097/00005768-200109000-00020

Halaki, M., & Ginn, K. (2012). Normalization of EMG Signals : To Normalize or Not to Normalize and What to Normalize to ? INTECH. Retrieved from http://dx.doi.org/10.5772/49957

Hyong, I. H., & Kang, J. H. (2013). Activities of the Vastus Lateralis and Vastus Medialis Oblique Muscles during Squats on Different Surfaces. Journal of Physical Therapy Science, 25(8), 915–917. https://doi.org/10.1589/jpts.25.915

Joseph F. Signorile, Brad Weber, Brad Roll, Joh F Caruso, I. owensteyn. (1994). An_Electromyographical_Comparison_of_the Squat and Knee Extension Exercises. Journal of Strength and Conditioning Research.

Lubahn, A. J., Kernozek, T. W., Tyson, T. L., Merkitch, K. W., Reutemann, P., & Chestnut, J. M. (2011). HIP MUSCLE ACTIVATION AND KNEE FRONTAL PLANE MOTION DURING WEIGHT BEARING THERAPEUTIC EXERCISES. *International Journal of Sports Physical Therapy*, *6*(2), 92–103

Medina, Jennifer M, et al. “Timing of Neuromuscular Activation of the Quadriceps and Hamstrings Prior to Landing in High School Male Athletes, Female Athletes,

and Female Non-Athletes." *Journal of Electromyography and Kinesiology* , vol. 18, no. 4, Aug. 2008, pp. 591–597. *Science Direct*, www.sciencedirect.com/science/article/pii/S1050641106001805.

Neitzel, J. a., & Davies, G. J. (2000). The Benefits and Controversy of the Parallel Squat in Strength Training and Rehabilitation. Strength and Conditioning Journal, 22(3), 30. https://doi.org/10.1519/1533-4295(2000)022<0030:TBACOT>2.0.CO;2

N.A. (N.D.). Amplitude Analysis: Normalization of EMG to Maximum Voluntary Contraction (MVC). Delsys. Retrieved April 13 2018 from: https://www.delsys.com/emgworks-analysis-techniques-using-emgscript/

Nishiwaki, G. A., Urabe, Y., & Tanaka, K. (2006). EMG Analysis of Lower Extremity Muscles in Three Different Squat Exercises. Journal of the Japanese Physical Therapy Association, 9(1), 21–26. https://doi.org/10.1298/jjpta.9.21

Paoli, A., Marcolin, G., & Petrone, N. (2009). The Effect of Stance Width On The Electromyographical Activity of Eight Superficial Thigh Muscles During Back Squat With Different Bar Loads. Journal of Strength and Conditioning Research, 246–249

RA, van der H., NE, L., R, van L., SMA, B.-Z., & M, van M. (2015). Exercise for treating patellofemoral pain syndrome (Review). Cochrane Database of Systematic Reviews, (1), 199. https://doi.org/10.1002/14651858.CD010387.pub2.www.cochranelibrary.com

Sampaio-jorge, F., Rodrigues, M. R., Magini, M., Paula, R. P. De, & Silva, R. (2011). Optimization proposal for squatting exercise: An EMG analysis. Journal of Physical Education and Sports Management, 2(August), 37–43.