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ELECTROMYOGRAPHIC ACTIVITY OF THE LOWER LIMB MUSCLES DURING SQUAT EXERCISE AND ITS DERIVATIVES: A SYSTEMATIC REVIEW WITH META-ANALYSIS

ACTIVIDAD ELECTROMIOGRÁFICA DE LOS MÚSCULOS DE LA EXTREMIDAD INFERIOR DURANTE EL EJERCICIO DE SENTADILLAS Y SUS DERIVADOS: UNA REVISIÓN SISTEMÁTICA CON METAANÁLISIS

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Abstract

The systematic review and meta-analysis aimed to assess electromyographic activity in various types of squats against back squats to provide insights for training recommendations and injury prevention. Eight studies were reviewed, seven included in the meta-analysis, comparing back, front, overhead, and belt squats. Overall, no significant differences in muscle activation were found among squat types, with standardized mean differences ranging from -0.49 to 0.66. Specifically, front and back squats showed similar electromyographic activity levels. Limited evidence for overhead and belt squats prevented comprehensive comparisons, but one study indicated lower activity in back squats compared to overhead squats (-0.47) and similar levels compared to belt squats (0.09). The study quality was moderate, with robustness and absence of publication bias noted. This analysis underscores the complexity of muscle engagement during different squat variations, suggesting that training emphasis on specific muscles should consider individual needs and goals.

Keywords: Activation, muscle, myoelectrical activity, performance, strength training.

Resumen

La revisión sistemática y el meta análisis tuvieron como objetivo evaluar la actividad electromiográfica en varios tipos de sentadillas en comparación con el ejercicio de back squat para proporcionar recomendaciones de entrenamiento y prevención de lesiones. Se revisaron ocho estudios, de los cuales siete se incluyeron en el metaanálisis, comparando las sentadillas de espalda, frontal, con barra sobre la cabeza y con cinturón. En general, no se encontraron diferencias significativas en la activación muscular entre los diferentes tipos de sentadillas, con diferencias medias estandarizadas que oscilaron entre -0.49 y 0.66. Específicamente, las sentadillas frontales y de espalda mostraron niveles similares de actividad electromiográfica. La evidencia limitada para las sentadillas con barra sobre la cabeza y con cinturón impidió comparaciones exhaustivas, pero un estudio indicó una menor actividad en las sentadillas de espalda en comparación con las sentadillas con barra sobre la cabeza (-0.47) y niveles similares en comparación con las sentadillas con cinturón (0.09). La calidad de los estudios fue moderada, con robustez y ausencia de sesgo de publicación destacados. Este análisis subraya la complejidad de la participación muscular durante las diferentes variaciones de sentadillas, sugiriendo que el énfasis en el entrenamiento de músculos específicos debe considerar las necesidades y objetivos individuales.

Palabras clave: Actividad mioeléctrica, activación, entrenamiento de fuerza, músculo, rendimiento.

Introduction

Among the squat exercises we can find several types. For instance, the back squat exercise is considered the basic movement training, and it is used in strength training by trained and untrained athletes (Glassbrook et al., 2017). Moreover, squat training enhances strength and jump performance, which improves the athletes' overall performance (Weber et al., 2008). The squat, whether back, front, or belt, has been widely studied by comparing biological implications (Jones et al., 2012; Shaner et al., 2014), biomechanics (Gomes et al., 2015; Mehls et al., 2020), and transference from training (Bloomquist et al., 2013; Domire & Challis, 2007). Indeed, two reviews and meta-analyses have been carried out, providing benchmarks for training standardization by showing the direct relationship between stance width and hip rotation muscles activity, absolute external load and trunk muscle recruitment, use of unstable floor and muscle activation, and even the relationship between muscle activity and the depth squat or using of weight belts (Clark et al., 2012; Glassbrook et al., 2017). Also, several studies have shown key points of training related to the squat training set-up, such as foot placement (David & Bird, 2014), barbell placement (high bar or low bar) (Murawa et al., 2020), or depth (knee flexion angle) during the execution of squats (Caterisano et al., 2002; Contreras et al., 2016; O'Neill & Psycharakis, 2021), to enhance performance. Nevertheless, meta-analyses or reviews have not been conducted to compare several types of squat exercises, despite the exercises' variability identified as an important variable for enhancing performance (Baz-Valle et al., 2019; Kassiano et al., 2022).

In this sense, the selection of resistance training squat derived exercises is a variable that could lead to specific adaptation (Yetter & Moir, 2008), since the inclusion of analogous resistance exercises (e.g. hang clean and mid-thigh clean) has been shown to have a specific influence on the improvement in the ability to produce strength quickly or achieve maximal strength (Suchomel et al., 2017). This seems to be linked to muscle involvement (Komi, 1984), which has been extensively studied by looking for the relationship between electromyographic activity and motor unit recruitment (Cram, 2003). Thus, knowing the involvement of muscles during exercise would be interesting for fitness coaches, as many injuries could be related to muscle imbalances and weakness, or joint asymmetry, among other parameters (Drigny et al., 2020; Nadler et al., 2001; Wang & Cochrane, 2001; Yeung et al., 2009). Therefore, the possible differences in electromyographic activity between squat exercises would allow specifically focusing on specific muscles to improve strength and performance.

In order to measure electromyographic activity, surface electromyography (sEMG) has often been used, as it is a non-invasive technique that is mainly used to detect the muscle's electrical activity (amplitude and frequency of muscle excitation) (Vigotsky et al., 2017). For this, several considerations have been proposed to homogenise procedures (Hermens et al., 2000; Konrad, 2005). To standardize the recording, processing, and interpretation of electromyographic signal the Surface EMG for Non-Invasive Assessment of Muscle consensus (SENIAM) was developed, although not all studies have considered it (Aspe & Swinton, 2014; Gullett et al., 2009; Yavuz et al., 2015). Nevertheless, several procedures can be found in the literature which could preclude the comparison of results between studies (Chauhan et al., 2016; Jung & Chae, 2017; Swinton et al., 2012). Therefore, a summary of results is needed, considering the characteristic that determines the comparison between studies.

Then, if electromyographic activity is assumed to be synonymous with the muscles' contribution in the resistance exercise (Konrad, 2005), the measurement of sEMG could show differences between the muscles involved in any exercise. Therefore, this meta-analysis focused on lower limb and trunk muscles whose electromyographic signals had been recorded during at least two squat exercises. In addition, the data had to have been normalised with respect to maximal voluntary contraction (MVC) in order to be able to compare exercises and muscles (Konrad, 2005) and reported as descriptive of the task. Consequently, the aim of this study was: (i) to summarise evidence related to sEMG in squat exercises, (ii) to compare the muscle activation of the semitendinosus, biceps femoris, vastus lateralis, vastus medialis, rectus femoris, gluteus maximus, gluteus medius, and erector spinae muscles in back squat versus another type of squat (front, overhead, and belt), and (iii) to provide recommendations for squat training and accurately compare muscle activation using sEMG.

Materials and Methods

Design

A systematic review of the literature and meta-analysis were conducted and reported following the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) guidelines (Page et al., 2021). The study was registered in the International Prospective Register of Systematic Reviews (CRD42022300356).

Data Source and Search

Potential studies were identified via a comprehensive strategy. The electronic database search encompassed PubMed, Scopus, EBSCO, and Web of Science databases. The search spanned from inception to March 7th, 2024, with an initial query and screening conducted on December 5th, 2021. Additionally, the databases were revisited from their inception dates to ensure comprehensive coverage. References from the included studies were searched for further relevant research.

A systematic search strategy was developed by collecting key items following the PICO strategy: (1) participants: active physically and healthy adults; (2) intervention: type of squat (front, overhead, and belt); (3) comparison: back squat; (3) outcomes: averaged electromyographic activity. The search strategy in Pubmed, Scopus, EBSCOhost, and Web of Science was the following: ("lower limb muscle*" OR "trunk muscle*" OR semitendinosus OR "biceps femoris" OR "vastus lateralis" OR "vastus medialis" OR "rectus femoris" OR "gluteus maximus" OR "gluteus medius" OR "erector spinae" OR longissimus OR multifidus OR "lumbar iliocostalis" OR quadriceps OR hamstring) AND squat* AND (front OR overhead OR belt) AND ("maximum voluntary contraction" OR "maximum voluntary isometric contraction" OR MVC OR "muscle activ*" OR "muscle excitation" OR electromyo* OR EMG OR sEMG OR "surface electromyography") NOT (syndrome OR injur* OR pain* OR disease)

Data Extraction and Selection Criteria

The screening process was performed in Rayyan software (Ouzzani et al., 2016). Two reviewers (J. M. and T.R.) independently collected and analysed the titles and abstracts retrieved from the literature search and reviewed the entire selected articles according to the inclusion criteria. Any disagreement between the reviewers regarding study inclusion and / or coding procedure was settled by a third researcher (J. M.O). Cohen's kappa coefficient (κ) was used to estimate inter-rater reliability (McHugh, 2012).

The corresponding authors of the included studies were contacted to request unpublished data that could potentially be relevant for the aim of this study. If relevant data was missing (e.g. means or electrode placement), this was required from the corresponding authors. The authors who did not respond after a month were contacted twice. The response rate was 37.5%.

The following inclusion criteria were considered: (i) studies comparing the sEMG during different types of squat (back squat, front squat, overhead squat, and belt squat) of the lower limb musculature, in a healthy population regardless of age, and sex, (ii) muscle activation had to be expressed as the relative to MVC, electrode location had to be specified as SENIAM or describing the followed procedures and electrode placement, (iii) the sEMG should have been recorded when lifting moderate-high weight loads (≥60% 1RM) or isometric contractions, (iv) only articles published in English were included, (v) therefore grey literature was dismissed. To minimize the influence derived from technical procedures between studies in the quantitative analysis, we only included articles that reported electromyographic activity in two parallel squats (Caterisano et al., 2002; Clark et al., 2012) (back squat and another -front, overhead or belt squat-). Likewise, only the studies which reported electromyographic activity in dynamic squats were included since isometric squats were reported in one only article.

The studies that met the inclusion and exclusion criteria were coded and stored in a spreadsheetaccording to muscle group and study. The main outcomes were the mean myoelectrical activity on the lower muscle limb, standard deviation, and number of participants analysed in each study. In addition, the outcomes were also sorted according to type of squat, intensity of testing (as percentage of one-repetition maximum), cadence, last repetition included in the sEMG analysis, muscle action, electrode placement, and sex of participants.

Outcomes

The sEMG was chosen according to their relationship with myoelectrical activity. Several authors (Glassbrook et al., 2017; Konrad, 2005) have shown how sEMG allow describing the muscle contribution on several exercises, as the signal is sensitive to changes in intensity, task, and fatigue, among others. In fact, constrains have been identified on procedures and analyses, which may be overcome by the relative measurement of sEMG (i.e. percentage of maximum voluntary contraction) (Nicholson, 2000). This way, a relative value could be considered as a valid and reliable index to compare changes in muscle activity between exercises, muscles and time (De Luca, 1997; Nicholson, 2000; Yang & Winter, 1984). Thus, the sEMG reported as a percentage of MVC appears to be a trustworthy index of muscle activity that allows comparisons between measurement times, muscle, and exercises. In addition, in order to show a more representative muscle activity of the entire range of movement regardless of intensity or cadence, the sEMG averages during a squat may provide a better comparison due to the kinematic movement similarities between the different types of squats (Renshaw et al., 2010).

Risk of Bias Assessment

Assessment of risk of bias was based on the tool for the assessment of Study quality and reporting in exercise (TESTEX) scale (Smart et al., 2015). This scale uses 12 criteria, with some of them having more than one possible point, for a maximum score of 15 points. Study quality is evaluated with up to 5 points and reporting up to 10 points.

Data Synthesis and Statistical Analysis

The statistical analyses were performed using software R version 4.0.2 in the RStudio environment (R Studio Inc., Boston, MA, USA) with the "meta" package (version 4.14), "dmetar" package (version 0.0.9000), and "metafor" package (version 2.4).

Effect Measure

Our analysis was based on a comparison of different types of squats with respect to each muscle activated, so our unit of analysis was the group (muscle) and not the study. The effect estimation was calculated using a random-effects model using the restricted maximum likelihood (REML) estimator for calculating within-study variance estimated (Langan et al., 2019). Thus, for each group, the standardized mean difference (SMD) was used as a corrected effect size (ES) index with a 95% confidence interval (CI), according to Morris (2000) and Becker (1988) (Eq.1). The SMD was defined as the difference between the means of back squat and another squat-type divided by the standard deviation of the back squat, then corrected by the factor for small samples (dfE,C) (Morris, 2008). The statistical significance threshold was established using a p value < .05. Effect size threshold values were 0.2 for small effect, 0.5 for moderate effect, and 0.8 for large effect (Cohen, 1988).

$$SMD = \frac{M1 - M2}{SD2} \cdot Factor$$

Where M1 is mean of muscle activity in front, overhead, or belt squat; M2 is mean of muscle activity in back squat; SD2 is standard deviation of muscle activity in back squat; and Factor is the correction factor for small samples according to Morris's and Becker's criterion.

Reporting Heterogeneity and Bias Assessment

The degree of heterogeneity between studies was determined by using the I2 statistic. The heterogeneity was interpreted depending on I2 magnitude as no heterogeneity (< 25%), low heterogeneity (25–49.9%), moderate heterogeneity (50–74.9%), and large heterogeneity (> 75%) (Higgins & Thompson, 2002). To explore the robustness of our study, a sensitivity analysis was carried out by the following test. Potential outliers were examined by influence analyses (Cook's distance) (Viechtbauer & Cheung, 2010), and by visual inspection of the forest plot for ES and I2 according to the outlier-labelling rule (Tukey, 1977). Also, a publication bias analysis was carried out using the three-parameter selection model (3PSM), as its use is recommended when a high degree of heterogeneity is suspected (Carter et al., 2019). 3PSM was performed to estimate both unadjusted and adjusted meta-analytic models in a simple model with a single cut-off point (< .05) and no moderators. Both estimations models were subsequently compared using a likelihood-ratio test in which a significant result suggested the presence of publication bias (Coburn & Vevea, 2016).

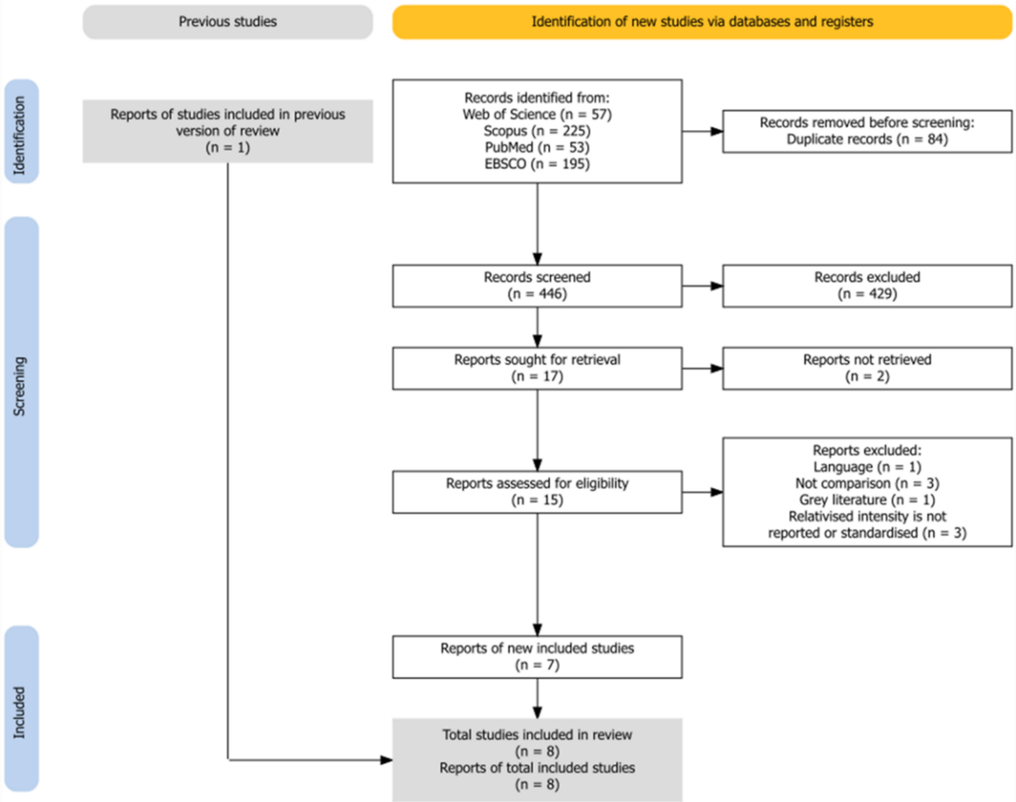
Results

Search Results

The literature search process provided a total of 530 research studies. Initially, all duplicates were removed (84 reports). A total of 446 remained, and a further 429 were removed after screening using the titles and abstracts. The full text of the remaining 17 reports were reviewed for a more detailed evaluation and resulted in the exclusion of another 10 reports (two of themcould not be retrievedin full text). Based on the eligibility criteria for review, 7 reports were finally included in the analysis. The studies that were included in the previous version of the review but were not identified in this update were added in this step (Figure 1). Thus, this update included a total of 8 reports. The inter-coder reliability Cohen's Kappa was higher than .80 (an almost 64% agreement).

Figure 1

Selection of Studies Included in the Review and Meta-Analysis. PRISMA Flowchart



General Characteristics

The characteristics and details of every study are presented in Table 1. There were 63 participants in 5 studies that compared the front and back squats. Only one study compared the overhead and back squats (*n* = 14), and another that compared the belt and back squats (*n* = 31). The participants were trained and untrained athletes of both sexes and were aged between 18 and 35 years old. For the sEMG signal recording, treatment and analysis, most of the studies used the SENIAM electrode guidelines placements, although a few others did not meet the consensus placement or, at least, it was not reported. The repetitions analysed were between one and ten, as well as intensity, and the squats performed were between 60% and 100% 1RM. Also, a mixed squatting cadence was used in some studies (between 0.5 to 3 s per eccentric and concentric movement, including free cadence. See table 1).

Table 1a

Characteristics, Procedures, and Signal Treatment of Studies Included in the Review

Article	Participants	Exercise	Depth	Muscle	Metric	Treatment	RMS windows (s)	Value reported	Repetitions analysed	Action	Electrode	Sex	Intensity	Cadence (s)	MVC length	Normalization's exercise	Joint degree in MVIC (knee/hip)	Normalization's muscle action
Aspe & Swinton (2014)	14 elite male rugby players (26 + 7 years 90.5 + 17.5 kg)	Back squat Overhead squat	Parallel	Gluteus maximus Vastus lateralis Biceps femoris Erector spinae	%MVIC	Integrated	N.A.	mean of all data recorded	3	ECC CON	Others	Men	60% 3RM 75% 3RM 90% 3RM	3 0 X 0	5	Hip extension Squat Knee flexion Trunk extension	N.A.	Isometric
Contreras et al. (2016)	13 resistance-trained women (28.9 +5.1 years 58.2 + 6.4 kg)	Back squat Front squat	Parallel Full	Biceps femoris Gluteus maximus Vastus lateralis	%MVIC	RMS	0.10	mean and max of all data recorded	10	CON/ECC	SENIAM	Women	10 RM	Free	N.A.	Knee flexion Hip extension Knee extension	45/0 90/0 90/90	Isometric
Coratella et al. (2021)	10 men competitive bodybuilder (29.8 + 3.0 years 77.9 + 1.0 kg)	Back squat Front squat	Full Parallel	Erector spinae Gluteus maximus Gluteus medius Rectus femoris Vastus lateralis Vastus medialis	%MVIC	RMS	0.025	mean of all data recorded	6	CON ECC	SENIAM	Men	80% 1RM	2 0.5 2 0	5	Trunk extension Hip extension Hip abduction Knee extension	N.A.	Isometric

Table 1b

Characteristics, Procedures, and Signal Treatment of Studies Included in the Review

Article	Participants	Exercise	Depth	Muscle	Metric	Treatment	RMS windows (s)	Value reported	Repetitions analysed	Action	Electrode	Sex	Intensity	Cadence (s)	MVC length	Normalization's exercise	Joint degree in MVIC (knee/hip)	Normalization's muscle action
Evans et al. (2019)	31 participants (23.1 + 2.4 years 75.8 + 13.2 kg)	Back squat Belt squat	Parallel	Gluteus maximus Vastus lateralis Rectus femoris Vastus medialis	%MVIC	RMS	0.50	max and mean of all data recorded	5	CON/ECC	SENIAM	Mixt	5 RM	Free	3	Squeeze	-	Isometric
Gullet et al. (2009)	15 participants (9 men 6 women 22.1 + 3.6 years 69.7 + 6.2 kg)	Front squat Back squat	Parallel	Biceps femoris Rectus femoris Semitendinosus Vastus lateralis Vastus medialis Erector spinae	%MVIC	EMG normalised	N.A.	mean of all data recorded	2	CON ECC	Others	Mixt	70% 1RM	Free	5	Knee flexion Knee extension Trunk extension	N.A.	Isometric
Korak et al (2018)	13 women (22.8 + 3.1 years 73.4 + 14.0 kg)	Back squat Front squat	Parallel	Gluteus maximus Vastus medialis Vastus lateralis Rectus femoris Biceps femoris	%MVC	RMS	rep's length	mean of peak data recorded	3	CON/ECC	SENIAM	Women	75% 1RM	2 0 1 2	N.A.	Squat	N.A.	Dynamic

Table 1c

Characteristics, Procedures, and Signal Treatment of Studies Included in the Review

Article	Participants	Exercise	Depth	Muscle	Metric	Treatment	RMS windows (s)	Value reported	Repetitions analysed	Action	Electrode	Sex	Intensity	Cadence (s)	MVC length	Normalization's exercise	Joint degree in MVIC (knee/hip)	Normalization's muscle action
Trindade et al (2020)	10 healthy trained men (30.7 +- 7.9 years; 85.2 +- 13.7 kg)	Back squat Front squat	Parallel Partial Full	Rectus femoris Vastus lateralis Vastus medialis Biceps Femoris Gluteus maximus Erector spinae	%MVIC	RMS	N.A.	Max of signal	-	ISO	Others	Men	-	-	10	Knee extension Knee flexion Back extension Hip extension	60/20	Isometric
Yavuz et al. (2015)	12 healthy men (21.2 + 1.9 years)	Back squat Front squat	Parallel	Rectus femoris Vastus medialis Vastus lateralis Erector spinae Gluteus maximus Biceps femoris Semitendinosus	%MVIC	RMS	0.10	mean of all data recorded	1	CON/ECC ECC CON	Others	Men	1 RM	Free	3	Knee extension Trunk extension Hip extension Knee flexion	90/90 0 0/-20	Isometric

Notes: Cadence is reported as seconds in eccentric contraction, pause transition, concentric contraction, and pause at the end of movement respectively. %MVIC = percentage of maximum voluntary isometric contraction; %MVC = percentage of maximum voluntary contraction; RMS = root mean square; ECC = eccentric contraction reported in isolation; CON = concentric contraction reported in isolation; CON/ECC = concentric and eccentric contraction reported together; ISO = isometric contraction reported. N.A. = non-available data.

Risk of Bias in Studies

The TESTEX scale for risk of bias showed a score between 7 and 10 points in the 15-point range (Table 2). Therefore, the quality of the studies included in this meta-analysis could be considered moderate. The principal concerns were that studies showed a non-concealed allocation group, and no adverse events were reported. Other items such as exercise attendance and reporting baseline differences between groups were also unsatisfied. However, this was not a major issue, as the included studies were descriptive of a single session.

Table 2

TESTEX Assessment of the Quality and Reporting of Exercise Training Studies Examining Muscle Activation in Squats

	Study quality criterion						Study reporting criterion											
Study	**1**	**2**	**3**	**4**	**5**	**Total**	**6a**	**6b**	**6c**	**7**	**8a**	**8b**	**9**	**10**	**11**	**12**	**Total**	**Overall total**
Aspe & Swin (2014)	1	0	0	0	1	2	1	0	0	0	1	0	1	1	1	1	6	8
Contrer al. (2016)	1	1	0	0	1	3	1	0	0	0	1	1	1	1	1	1	7	10
Coratell al. (2021)	1	1	0	0	1	3	1	0	0	0	1	0	1	1	1	1	6	9
Evans et al. (2019)	1	1	0	0	1	3	1	0	0	0	1	0	1	1	1	1	6	9
Gullet et al. (2009)	1	1	0	0	1	3	1	0	0	0	1	1	1	1	1	1	7	10
Korak et al (2018)	1	0	0	0	1	2	1	0	0	0	1	0	1	1	1	1	6	8
Trindad al (2020)	1	0	0	0	1	2	1	0	0	0	1	1	1	1	1	1	7	9
Yavuz et al. (2015)	1	0	0	0	1	2	1	0	0	0	1	0	1	0	1	1	5	7

Item 1 = Eligibility criteria are clearly stated and fulfilled; Item 2 = Method is described and they are truly random; Item 3 = Group allocation is concealed from participants eligible for inclusion in the trial; Item 4 = Baseline data are separated by group allocation, presented and no differences are apparent; Item 5 = Blinding of assessor for at least one key outcome; Item 6a = Outcome measures assessed in 80% of participants; Item 6b = Adverse events are reported; Item 6c = Exercise attendance is reported; Item 7 = Intention-to-treat analysis; Item 8a = Between-group statistical comparisons are reported for at least one primary outcome measure of interest; Item 8b = Between-group statistical comparisons are reported for at least one secondary outcome measure of interest. Item 9 = All outcomes are reports with point estimates; Item 10 = Activity monitoring in control groups; Item 11 = Relative exercise intensity remained constant; Item 12 = Exercise volume and energy expenditure can be calculated.

Sensitivity Analysis and Publication Bias

Influence analysis revealed the robustness of the results for muscles in the front and back squats comparison (supplemental S1-3). No outliers were identified. Afterwards, the 3PSM analysis performed suggested the non-presence of publication bias for the front squat comparison ($X_1^2 = 3.27$; *p* = .071).

Results of Individual Studies

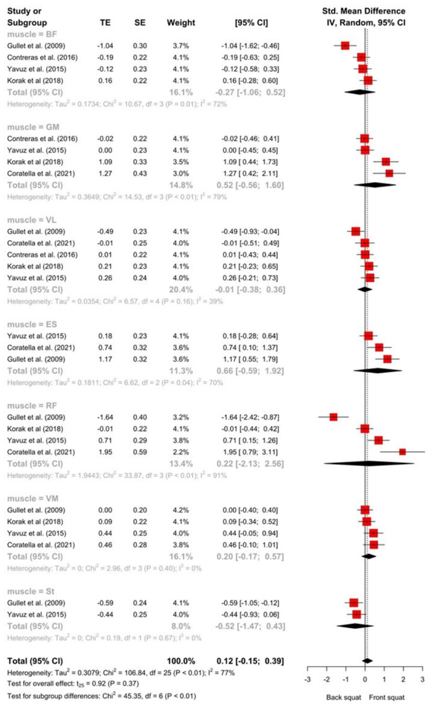
Front Squat vs Back Squat

Pooled analyses did not show differences in overall muscle activity in front squat as compared to the back squat (Figure 2). Nevertheless, a subgroup analysis found differences between muscle groups (QBetween = 45.35; *p*< .001) despite none of the muscle groups showing a significant effect. In this case, only the erector spinae (*k* = 3; *n* = 37; SMD+ = 0.66 [95%CI = -0.59, 1.92]; I2 = 70%), and gluteus maximus (*k* = 4; *n* = 48; SMD = 0.52 [95%CI = -0.56, 1.60]; I2 = 79%) showed a moderate effect in favour of the front squat, although uncertainty and moderate-large heterogeneity were found. Whilst for the rectus femoris (*k* = 4; *n* = 50; SMD+ = 0.22 [95%CI = -2.13, 2.56]; I2 = 91%), and vastus medialis (*k* = 4; *n* = 50; SMD+ = 0.20 [95%CI = -0.17, 0.57]; I2 = 0.0%) a small effect was highlighted in favour of the front squat, although a large heterogeneity was found. In favour of the back squat, a moderate effect was shown in the semitendinosus muscle (*k* = 2; *n* = 27; SMD+ = -0.52 [95%CI = -1.47, 0.43]; I2 = 0.0%). In addition, small and trivial effects were found in the biceps femoris (*k* = 4; *n* = 53; SMD+ = -0.27

[95%CI = -1.06, 0.52]; I2 = 72%), and vastus lateralis (*k* = 5; *n* = 63; SMD+ = -0.01 [95%CI = -0.38, 0.36]; I2 = 39%) with a low-moderate heterogeneity.

Figure 2

Forest Plot by Front Squat and Back Squat Comparison in Muscle Activation



BF = biceps femoris, ES = erector spinae, GM = gluteus maximus, RF = rectus femoris, VL = vastus lateralis, VM = vastus medialis. TE = total effect (standard mean difference), SE = standard error, 95%CI = 95% of confidence interval, Std = standard

Overhead Squat vs. Back Squat

Only one study reported a comparison between the overhead and back squats. Despite not being able to find a conclusive result due to lack of evidence, the authors still provided advice on the use of the different squats for training different muscle groups (Aspe & Swinton, 2014). The confidence interval of the experimental group tended to indicate that the back squat achieved a greater muscle activation in biceps femoris¸ erector spinae, and gluteus maximus than overhead squat as intensity increased.

Belt Squat vs Back Squat

Only one study reported a comparison between the belt and back squats. Just as with the overhead squat, Evans et al. (2019) recommended the use of the belt squat as an alternative to the back squat. Only gluteus maximus and vastus lateralis showed a difference in activation regarding back squat.

Discussion

The current meta-analysis is based on studies that compared several squat exercises. The meta-analysis summarizes the results of 56 effect sizes from 7 studies involving over 858 records and 108 participants, resulting in similar activations in each muscle group were observed between the back and front squats.

The overall results in the meta-analysis did not show differences between the back and front squats. Likewise, the analysis of the subgroups according to muscles showed similarities in muscle activation with some heterogeneity. For the above reasons, the meta-analysis results for the front squat could agree with previous literature showing similar electromyographic activity between exercises (in range of 50-60% MVC) despite utilizing isometric contraction (Trindade et al., 2020), and against of assumption of the bar swipes position from the back to the front of the trunk could influence muscle activation (SMD+ = 0.66 [95%CI = -0.59, 1.92]). Previous studies showed that myoelectrical activity during the squat could be related to the type of squat, as since load placement could have an influence on the centre of pressure being forward projected in the front squat which is compensated by hip extension (Robertson et al., 2008; Swinton, Stewart et al., 2012), conditioning the intra-muscle coordination (Krishnamoorthy et al., 2003). Indeed, Glassbrook et al. (2017) identified that changes in placement of load in the back squat had an influence on trunk inclination and, as consequence, in myoelectrical activity. Taking into account this review, a higher sEMG was observed in the erector spinae, adductors, and gluteal muscles when the bar was placed on the lower trapezius just below the spinous process of the C7 vertebra, whilst the bar placement across the top of the trapezius showed a higher activation of the quadriceps. Moreover, front squat decreased trunk flexion and pelvis anterior tilt angles whilst low-back extension (Goršič et al., 2020) and mechanical demand in lower limb muscle (Krzyszkowski & Kipp, 2020) increased. Therefore, differences between the myoelectrical activity of the back squat and front squat exercises might have been expected, as an increased force moment was related to increased muscle participation (Schick et al., 2010; Wretenberg et al., 1993). Lastly, the lack of significant results could be explained by the high heterogeneity found in the analysis which might be related with sample size, length of the series, time under tension, cadence, participants, signal normalization, and studies design that are discussed on successive paragraph.

Consequently, the results could have been influenced by several conditions. For example, the Rectus femoris showed a small effect size. The effect in favour of the front squat in Coratella et al. (2021) study could have been influenced by design, as the participants had to perform squatting close to failure, with a slow rhythm, and brief isometric contraction in the transition between eccentric and concentric contractions. In this sense, a longer time under tension and heavy loads have shown to increase the sEMG signal, as compared with another condition such as short volume and light loads (Corradi et al., 2021). Contrary to this, Gullet (2009) favoured the back squat using a free cadence and few repetitions, so the results may not have been influenced by potential fatigue effects such as in Coratella's study. Also, the disagreement between studies on the hip extensor musculature analysed (gluteus maximus) may be due to the cadence of the squat (Keogh et al., 1999). Coratella et al. (2021) and Korak et al. (2018) used "2-0-1-2" and "2-0.5-2-0" seconds for eccentric, isometric, concentric, and pause, respectively opposite to the free cadence that Contreras et al. (2016) and Yavuz et al. (2015) allowed. Thus, the free cadence may have given rise to each squat being performed at a different cadence, and thus the real muscle activation could have been hidden by the velocity of muscle contraction (Miller et al., 2012).

Regarding biceps femoris activation, only Gullet (2009) showed a strong effect favouring the back squat, which could be due to the participants' previous expertise. In this study, the participants must have had at least one year of experience training with the back and front squats once a week, while in other studies, three (Korak et al., 2018) or seven (Contreras et al., 2016) years of experience were required. Expertise has been related to higher muscle activity as a consequence of the optimization procedure of motor units' recruitment (Bernardi et al., 1996). Seemingly, expert athletes are able to achieve higher a sEMG signal a compared with beginners (Goubault et al., 2020). Therefore, the training background should be considered as a variable likely to have a high potential influence.

Another reason for the results found could be related to how the recording of the sEMG was performed. In this sense, some studies included in this meta-analysis were conducted outside the SENIAM consensus, despite the placement of the electrodes suggested to have an influence on signal recording in muscle and exercise such as the pectoris major (Król et al., 2007) or deadlift (Martín-Fuentes et al., 2020). Moreover, the number of repetitions performed has been identified as a disturbance in sEMG analysis, as the signal is influenced by fatigue (Venugopal et al., 2014). Georgakis et al. (2003) and Masuda et al. (1999) reported that the changes in the signal over exercise-induce fatigue showed an increase in the amplitude domain and a decrease in the frequency domain. Therefore, as the number of repetitions performed closer to muscle failure increases, the myoelectrical activity from squatting may be overestimated due to the influence of fatigue level (González-Izal et al., 2010). In addition, how the squat is performed may have an influence on the electromyographic signal. Two articles did not provide information on how the depth of the squat was ensured (Contreras et al., 2016; Coratella et al., 2021), whilst others monitored it with visual and verbal feedback (Aspe & Swinton, 2014). Since a flexible depth of squat criteria might imply undesirable range of movement (Caterisano et al., 2002), a strongly recommended strategy is to place a bungee cord or stick parallel to the height of each participant to mark the lowest point of the squat (Korak et al., 2018). Thus, muscle activation outside of the depth of the squat objective could contaminate the record, as the electromyographic signal is sensitive to angle at peak torque and muscle length (Lunnen et al., 1981).

All the studies' characteristics should have been analysed as moderator variables in a meta-regression, but in this meta-analysis, this meta-regression could not be carried out because of the low number of studies and data reported in them.

According to Fu et al. (2011) at least 6 to 10 studies by subgroup are needed to examine potential sources of variance in heterogeneity.

Limitations of the Review and Meta-Analysis

The current meta-analysis was conducted assuming several concerns that should be considered when interpreting the results. All the studies included used different methodological procedures (e.g. participants, relative loads, cadence, normalization and signal treatment), and this could give rise to the heterogeneity observed and the inconsistent results. Also, observations are lacking to ensure the accuracy of the results. In fact, the muscle with the most records was vastus lateralis (n = 63), and the one with the least was erector spinae (*n* = 27). Another reason for this likely inaccuracy is the low statistical power, as many groups of analysis were observed in only up to 4 studies (Higgins & Green, 2011). Therefore, the degree of certainty of this review and meta-analysis may be low, and the effect may be different from the observed estimate. Nevertheless, despite the high heterogeneity in the methods utilized among these studies, this meta-analysis may provide advice on several aspects that are needed to analyse the possible differences between the various types of squats. These are discussed as practice implications and perspectives bellow.

Future study designs should (i) be carried out comparing low, moderate, and high intensity separately (preferable as a percentage of 1RM); (ii) report the expertise of participants as years of experience and 1RM-body weight ratio; (iii) place electrodes according to the SENIAM consensus; (iv) ask the participant to perform the concentric phase of the squat exercise as fast as possible; (v) separately report muscle activity in the concentric and eccentric phases, showing mean and peak values according to every muscle as a percentage of MVIC isolated; (vi) mixed sex cohorts could be implemented, as similar motor units recruitment strategies between women and men have been reported (Guo et al., 2022); (vii) analyse the first repetition of each squat-type to avoid exercise fatigue induced; (viii) standardize squat height (preferably as a parallel squat) of every participant with a bungee cord or similar device; (ix) integrate the latest methodological consensus regarding electromyographical activity in order to enhance performance and reporting, as exemplified by initiatives such as the CEDE project (Besomi et al., 2024).

Practical Applications

This meta-analysis has applicability for resistance training, as it showed the similarity in the muscle activity in two types of squats. The main finding of this meta-analysis is that there is no difference in muscle activation between the front and back squats in the parallel squat, although widespread results were found. Then, both front and back squats could be used interchangeably as lower limb resistance training exercises. Indeed, the back squat typically enables the lifting of heavier weights compared to the front squat, making it advantageous for strength-focused goals. However, for those aiming for muscle hypertrophy, incorporating variations such as the back, front, overhead, and belt squat into training programs could provide a comprehensive approach to muscle growth (Kassiano et al., 2022). Nevertheless, the little evidence and high heterogeneity found need to be further explained through more research.

Ethics Committee Statement

Not applicable due to the type of scientific study, which is a systematic review.

Conflict of Interest Statement

The authors declare no conflicts of interest. The affiliating entities or institutions had no influence on the design of the study, the analysis of the data, or the interpretation of the results.

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Authors' Contribution

Adrián García-Valverde: Conceptualization, Data curation, Formal analysis, Resources, Visualization, Writing – original draft. Jacobo A. Rubio-Arias: Formal analysis, Methodology, Resources Writing – review & editing, Validation. José M. Oliva-Lozano: Investigation, Writing – review & editing. Tiago D. Ribeiro: Investigation, Data curation, Writing – review & editing. José M. Muyor: Conceptualization, Investigation, Project administration, Writing – review & editing, Supervision.

Data Availability Statement

Data available in the fig sharerepository (https://figshare.com/s/f1fc26236f67a22208c2)

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