

Knee extensor electromyographic activity during different depths of squat exercise in strength training experienced adults: A Systematic Review

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HIGHLIGHTS

- Squatting is an exercise that elicits lower-limb strength, hypertrophy, and power.
- The knee extensors are similarly activated at deep and partial squatting exercises.
- Knee extensor mechanical disadvantage is observed at deep squat.
- Hip extensors and ankle plantarflexors are more activated at the deep squat.
- This activation change among synergistic muscles in squat needs deeper evaluation.

ABBREVIATIONS

BWL	Body-weight load
EMG	Electromyography
RM	Repetition maximum
ROM	Range of motion

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BACKGROUND: Changes in range of motion during partial and deep squats can affect the electrical activity of the knee extensor muscles. There are results' divergences between studies that evaluated the effects of deep and partial squats on the electrical activity of the knee extensor muscles.

AIM: To systematically review the literature on the electromyographic activity of the knee extensor muscles during partial and deep squat exercises in subjects with strength training experience.

METHOD: The search included MEDLINE (via Pubmed), Scielo, EMBASE, in addition to a manual search, until June 2023. Cross-sectional observational studies comparing partial squats (up to 90° of knee flexion) and deep squats (maximum knee flexion) that evaluated the electrical activation through surface electromyography in men and women with strength training experience were included. Methodological quality assessment was performed using the adapted Downs and Black tool, as suggested by the Cochrane Collaboration. PROSPERO Registration number: CRD42022299829.

RESULTS: Of the 636 articles identified, four studies were included. The included studies presented electromyographic values (average or peak) of the two squat variations (partial and deep). No difference was found in the activation of the rectus femoris, vastus medialis and vastus lateralis muscles between partial and deep squats. Regarding methodological quality, one study was classified as having moderate (11/18) and the other three studies showing high methodological quality (13/18, 13/18 and 15/18).

CONCLUSION: The similarity in the knee extensors' electromyographic activation between partial and deep squat exercises in men and women with strength training experience suggests that both exercises can be used for recruiting these muscles during physical fitness activities. However, the reduced number of included studies, as well as the reduced number of subjects, suggest that new evidence is needed to clarify the potential acute effects of squat training variations in this population.

KEYWORDS: Electromyography | Knee extensors | Partial squat | Deep squat | Strength training | Observational studies

INTRODUCTION

Squatting is a movement that is part of the motor repertoire of human beings since childhood¹. It is also one of the most popular exercises used to elicit lower-limb strength, hypertrophy, and power^{1,2}. It has been used in strength training, functional training, rehabilitation and sports, and it may be applied to improve strength in the concentric and eccentric phases of the jump^{2,3}, during functional tasks such as the sit-to-stand task, as well as when picking up and throwing objects.

This movement is composed of an eccentric and a concentric phase, during which hip and knee extensors and plantar flexors are the primary movers involved during both the eccentric and the concentric phases^{3,4}. During squatting, the lower back muscles play an important role while stabilizing the upper body, and, consequently, the whole movement⁴. The squat exercise uses mono and biarticular

muscles, with a force variation that depends on joint position (due to changes in the moment arm and to the length-tension relationship)^{5,6}. In addition, squatting also represents a safe exercise for the knee joint, in view of the co-contraction of knee extensors and flexors that dynamically stabilize this joint⁷.

Among the available strategies to assess the degree of squatting effectiveness, surface electromyography (EMG) is one of the most used^{8,9,10}. EMG allows the analysis of the moment of recruitment and of the degree of activation of the involved muscles. More specifically, this technique captures the sum of action potentials from the recruited motor units (i.e., of the motoneurons and the muscle fibers they innervate) of a particular muscle region. Therefore, EMG is an important tool to identify how the squat and its variations may alter the knee extensor muscles' activity².

Different studies examined the knee extensor electrical activity during the squat exercise^{11,12}. Among the main results, there was a significant activation level of the monoarticular knee extensors. More specifically, the vasti muscles displayed values 30% to 90% higher than those of the rectus femoris muscle. As the rectus femoris is a biarticular muscle (with its origin in the pelvic anterior inferior iliac spine and insertion distally at the patella) acting simultaneously at the hip and knee joints, it seems to be more effective as a knee extensor when the trunk is more vertical, that is, when the muscle is in a more elongated position¹³. Therefore, it is reasonable to infer that muscle recruitment is influenced by different factors, such as joint range of motion (ROM), joint position, muscle and tendon length and exercise intensity^{11,12}.

The squatting's joint ROM can affect the muscle length-tension and torque-angle relationships. In addition, ROM affects the time under tension of the involved muscles, influencing the joint loads or work and, consequently, the degree of muscle activation. Therefore, changes in ROM during the squat affect the magnitude of the external load that can be used in the exercise, which can affect the degree of motor unit recruitment. Apparently, there seems to exist a greater demand on the musculoskeletal system in the deep squat compared to the partial squat, which suggests that a higher activation should be observed on the hip extensors, knee extensors and plantar flexors during the deep squat. However, there is a subjective feeling, during this deep movement execution, that the knee extensor is the muscle group that assumes this higher demand¹³.

Despite this commonly reported subjective feeling during squat practice, we did not find systematic review studies that compiled the existent evidence or verified possible effects of changing the squatting ROM on muscle activation. Although there may exist differences between studies due to very heterogeneous protocols, different instruments used for the analyses of the outcomes, sample size differences, and population heterogeneity, the apparent gap in the existent knowledge regarding the effects of changing the exercise demands on the involved muscles' electrical activity needs to be investigated. Thus, the purpose of this study was to systematically review the literature from observational studies regarding the knee extensor muscles' EMG activity during different depths of the squat exercises in healthy men and women with strength training experience.

METHODS

Study design

This systematic review was conducted and reported according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines¹⁴ and the Meta-analysis of Observational Studies and Epidemiology (MOOSE) guidelines¹⁵. The study was registered at the International Prospective Register of Systematic Reviews (PROSPERO), with the registration number CRD42022299829.

Search Strategy

The studies were selected from the electronic databases MEDLINE (by PubMed), EMBASE, and SciELO. The search was conducted until June 2023 and there was no restriction to publication year and language. In addition, a manual search was performed on the references from published studies on the subject. Controlled and uncontrolled descriptors were used for assessment, and outcome. Terms of the descriptors were used for the exercise type ("squat depth" OR "deep squat" OR "full squat" OR "parallel squat" OR "partial squat") and outcome (AND "electromyography", "EMG").

In the first selection phase, two reviewers (LR and ABC) independently assessed the titles and abstracts of the studies identified by the search strategy. All the abstracts that did not give sufficient information regarding the inclusion and exclusion criteria were selected for assessment of the complete article. In the second stage, the same reviewers independently assessed the complete articles and selected the studies in accordance with the eligibility criteria. Disagreements were resolved by consensus or, if necessary, a third evaluator (FCS) was consulted for studies inclusion or exclusion in the systematic review.

Selection criteria

All studies that evaluated the EMG of the knee extensors (rectus femoris, vastus lateralis and vastus medialis muscles) in partial and/or deep squat exercises in individuals with strength training experience were included. Opinion pieces, editorials, narrative reviews, systematic reviews, case studies, book chapters and conference abstracts were excluded.

Data extraction

The data were extracted by two independent reviewers (LR and ABC). The extracted data included characteristics of the participants (i.e., age, gender, height, body mass), methodological characteristics (i.e., study design, squat variation) and results of the outcome (mean and peak values of EMG signals). The main outcome extracted was the muscle activation of the vastus lateralis, vastus medialis and rectus femoris muscles using surface EMG.

Risk of Bias Assessment

The methodological quality of the selected articles was assessed by two reviewers, independently, using the Downs and Black Scale¹⁶, which was developed and validated for the assessment of the quality and risk of bias of randomized and observational studies. This tool is composed of 27 items that assess the domains “reporting”, “external validity”, “bias”, “confounding/selection bias”, and “power of the study”. To assess the observational studies, an adaptation suggested by the Cochrane Collaboration for the elaboration of a systematic review of observational studies was used¹⁷. According to this adaptation, items related to experimental studies, cohort, and case-control studies (items 4, 7, 8, 12, 13, 14, 15, 17, 19, 21, 22, 23, 24 and 27) were excluded because they did not fit the methodological design of the analyzed studies. Disagreements between the reviewers were resolved by consensus.

In this way, 17 items were considered, with a maximum sum of 18 points. Question 5 ranged from 0-2 points and question 27 was modified as it considered scores from 0-5 and was changed to 0-1, with 0 being considered when the study did not perform power or sample size calculation and 1 if any calculations were performed, according to Ratcliffe et al¹⁸. The methodological quality classification for each study followed the criteria adopted by other systematic review studies as follows: low quality ($\leq 33.3\%$), moderate quality (33.4-69.9%), and high quality (above 12 points) ($\geq 70\%$).

Data analysis

Qualitative data analysis was performed. For this analysis, the main features and results of included studies, in addition to the risk of bias, were presented and discussed.

RESULTS

Selection of studies

The comprehensive search strategy identified 636 papers for evaluation beyond title level, and 15 papers for full-text evaluation (Figure 1). On further evaluation of full texts (ABC and FCS), 11 papers were excluded. Therefore, four studies^{6,11,19,20} fulfilled all inclusion criteria and underwent critical appraisal.

Study characteristics

The studies were cross-sectional observational studies, which included 10 to 15 young subjects (mean age = 31 years) with strength training experience. Two studies were composed by men^{6,11} and two studies by women^{19,20} in their samples (Table 1).

Study procedures

Caterisano et al.¹¹ performed the squat in three conditions: partial squat, in which the angle between the femur and the tibia was approximately 2.36 rad (135°) at the knee joint; parallel squat, in which the angle between the femur and the tibia was approximately 1.57 rad (90°) at the knee joint; and full squat, in which the angle between the femur and the tibia was approximately 0.79 rad (45°) at the knee joint. Participants performed 3 repetitions with a fixed weight equivalent to 100-125% of each subject's body weight. Each participant was allowed at least 3 minutes of rest between trials.

Contreras et al.¹⁹ performed the squat in three conditions: for the front squat, the barbell was placed across the anterior deltoids and clavicles. Subjects fully flexed their elbows to position the upper arms parallel to the floor. During both back squat variations (full and parallel), the barbell was placed in the high bar position across the shoulders on the trapezius muscle, slightly above the posterior aspect of the deltoids. Participants performed 10 repetitions of their estimated 10 RM (10 maximal repetition or repetition maximum) of each respective variation. Subjects were given 5 minutes of rest between sets.

Da Silva et al.⁶ performed squats in two conditions: partial (0-90°) and full (0-140°) knee flexion. The subjects' feet were positioned at hip width and vertically aligned with the barbell position. The barbell was positioned on the shoulders (high-bar position) for all subjects and experimental conditions. Participants performed 10 repetitions of their estimated 10 RM of each respective variation. A rest period of 30-min was provided between conditions.

O'neil et al.²⁰ performed squat in four conditions: 90° knee angle depth + 23% bodyweight load (BWL); 90° knee angle depth + 38% BWL; 125° knee angle depth + 23% BWL; and 125° knee angle depth + 38% BWL. Knee angle was defined as the non-reflex angle between the femur and the tibia. A 90° knee angle squat was, therefore, deeper than a 125° knee angle squat (i.e., 55° of knee flexion from full extension). Participants performed 1 set of 7 repetitions for each of the four squat conditions, with 3 min rest between trials.

The four studies performed a familiarization test session.

Squat depth control

Caterisano et al.¹¹ controlled squat depth by requiring participants to maintain a consistent upper-body position for each trial. An investigator provided verbal cues for each subject when they were at the proper squatting depth, and proper depth was verified by cinematography analysis from the data collected during filming.

Contreras et al.¹⁹ controlled squat depth by requiring subjects to descend until the knees were maximally flexed in both the front and full squat. Descent during the parallel squat was limited to the point at which the tops of the thighs were parallel with the floor. No predetermined tempo was set.

Da Silva et al.⁶ determined the ROM by an electrogoniometer positioned at the knee joint, and all subjects performed both conditions in a self-selected cadence.

O'neil et al.²⁰ controlled squat depth by requiring participants to contact a metal rod at the end of the descending phase. Tempo was controlled by instructing participants to squat to a 65 beats per minute (bpm) metronome tone.

Electromyographic activity

Table 2 presents the EMG values (average or peak) of the squat variations from the four studies.

Caterisano et al.¹¹ observed that, when considering peak EMG activity during the upward (concentric) phase of the squat, the vastus medialis was significantly less active in the full squat than in the other 2 squatting depths (parallel and partial). No differences were found between partial, parallel, and full squats in the vastus lateralis' EMG activity.

Contreras et al.¹⁹ observed no differences in the vastus lateralis EMG activity between full, front, and parallel squats.

Da Silva et al.⁶ observed no differences in EMG activity of the vastus medialis, vastus lateralis and rectus femoris muscles between partial and full squats.

O'neil et al.²⁰ observed that mean activity of vastus lateralis was 1.3-1.4-fold greater at 90° than at 125° for 23 BWL and 38 BWL. Peak activity was 1.8-1.9-fold greater at 90° of knee flexion.

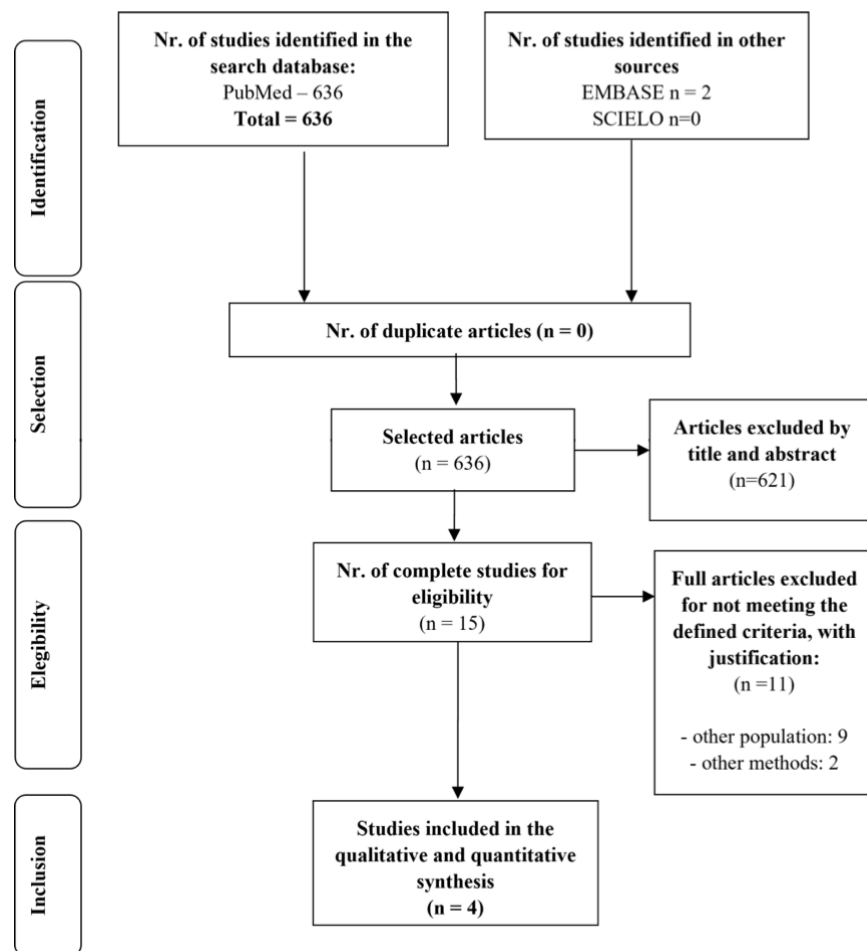


Figure 1. Flowchart of studies included in the review.

Table 1. Characteristics of included studies.

AUTHOR, YEAR	SAMPLE CHARACTERISTICS	OBJECTIVE OF THE STUDY	PROTOCOL
Caterisano et al., 2002	10 men (24.3±5.6 years) with 5years of experience in strength training.	Measure the relative contributions of 4 hip and thigh muscles while performing squats at 3 depths.	Two familiarization sessions were held. Squats were performed withthe weight between 100% and 125% of body weight. The tested muscles were the VL, VM, RF.
Contreras et al., 2016	13 women (28.9±5.1 years; height = 164±6.3 cm; body mass = 58.2±6.4 kg) with at least 3 years of experience in strength training.	To compare the amplitude of the VL's EMG activity in the front squat x full squat x parallel squat for 10 repetitions using loads estimated by the 10 RM test.	A familiarization session was held. Muscle activation during front squat, partial squat, and deep squat exercises was assessed through a randomized design. All subjects performed a 10 RM test for each squat condition. EMG was evaluated in the VL muscle.
Da Silva et al., 2017	15 men (26±5 years; body mass 80±8 kg) with 5 years of experience in strength training.	To assess muscle activation between partial and full squat exercise with external load equated on a relative basis between conditions.	Two familiarization sessions were held. A randomized design was used to assess muscle activation of the partial squat and full squat. All participants performed 10 RM test for each squat condition. EMG was evaluated in the VL, VM, and RF muscles.
O'Neill et al., 2021	10 women (41±9 years; body mass = 67.7±7.0 kg) who had participated in at least one bodypump class per week for a minimum period of 12 weeks.	To establish the squat load and squat depth effects on the EMG activity of theVL, GM, BF and GL in bodypump participants.	Two familiarization sessions were held. Squat load was determined in relation to body weight (23% and 38% of BWL) with a randomized design. EMG sensors were placed over VL.

BF: biceps femoris; BWL: bodyweight load; GL: gastrocnemius lateralis; GM: gluteus maximus; MVC: Maximum voluntary contraction; RF: rectus femoris; VL: vastus lateralis; VM: vastus medialis.

Table 2. Major findings for the partial squat vs deep squat (Mean EMG, values in microvolts).

AUTHOR, YEAR	MUSCLE	TYPE OF CONTRACTION	PARALELL SQUAT (Mean EMG ± SD)	PARTIAL SQUAT (Mean EMG ± SD)	DEEP SQUAT (Mean EMG ± SD)
Caterisano et al., 2002	Vastus Medialis	CON	18.85 ± 8.76	30.88 ± 16.18	20.23 ± 8.10
		ECC	43.25 ± 10.61	39.84 ± 10.26	43.21 ± 12.50
	Vastus Lateralis	CON	37.79 ± 13.37	38.82 ± 17.37	29.28 ± 10.72
		ECC	39.00 ± 12.42	38.34 ± 7.12	34.61 ± 10.30
Contreras et al., 2016	Vastus Lateralis	Total	110.35 ± 47.24		123.82 ± 67.42
Da Silva et al., 2017	Vastus Medialis	Total		48 ± 18.2	47 ± 18.02
	Vastus Lateralis		60 ± 17.3	55 ± 15.6	
	Rectus Femoris		61 ± 20	67 ± 20.2	
O'Neill et al., 2021	Vastus Lateralis	CON	23%		23%
			23.7 ± 5.1	18.2 ± 6.6	
			38%	38%	
		25.2 ± 5.1	19.2 ± 6.3		
	ECC	23%	23%		
		22.5 ± 3.9	15.9 ± 4.8		
38%		38%			
	23.8 ± 4.6	17.1 ± 5.1			

CON = concentric; ECC = eccentric; EMG = electromyography; SD = standard deviation.

Table 3. Major findings for partial squat vs deep squat (Peak EMG, in microvolts).

AUTHOR, YEAR	MUSCLE	TYPE OF CONTRACTION	PARALELL SQUAT (Peak EMG ± SD)	PARTIAL SQUAT (Peak EMG ± SD)	DEEP SQUAT Peak EMG ± SD)
Caterisano et al., 2002	Vastus Medialis	CON	28.85 ± 9.97	26.70 ± 7.34	19.29 ± 6.20*
	Vastus Lateralis		17.45 ± 12.43	20.46 ± 8.37	20.86 ± 9.37
Contreras et al., 2016	Vastus Lateralis	Total	243.92 ± 121.63		280.54 ± 166.16
O'Neil et al., 2021	Vastus Lateralis	CON	23% 53.4 ± 10.4		23% 28.6 ± 8.5
			38% 58.1 ± 13.3		38% 31.3 ± 9.0
		ECC	23% 51.5 ± 10.7		23% 29.1 ± 8.8
			38% 56.4 ± 12.4		38% 30.7 ± 8.5

CON = concentric; ECC = eccentric; EMG = electromyography; SD = standard deviation.

Risk of bias

Regarding the methodological quality, in general, moderate and high-quality values were observed for all analyzed items (Table 4). According to the proposed criteria from the Downs & Black scale, the total score of the 4 included studies ranged from 11 to 15 points, and the overall mean score was 13 ± 1.63 , with 1 study with moderate methodological quality (55.5% to 66.6%) and 3 studies classified with high methodological quality ($\geq 70\%$). The items that scored the most were "Reporting" and "Bias", showing that the studies had sufficient information to minimize the risk of assessments and results. The domains "External Validity", "Confusion" and "Power" were the ones that least scored and this infers that the studies had a moderate selection bias, with heterogeneous sample. While assessing the risk of bias for each item on the scale, the items related to "Reporting" of questions 1,2,3,6,7,10 were classified as having low risk of bias. The items related to the external validity of questions 11 and 13 were classified as having a moderate risk of bias, while items in questions 16, 17, 18 and 20 were classified as displaying low risk of bias. In the items of confounding factors, high and moderate risk of bias were found for questions 25 and 26, respectively. In the power item of question 27, moderate risk of bias was found.

Table 4. Risk of Bias Assessment.

<i>Items</i>	<i>Caterisano et al 2002</i>	<i>Contreras et al 2016</i>	<i>da Silva et al 2017</i>	<i>O'Neill et al 2021</i>	<i>Risk of bias for each scale item</i>
1. Is the hypothesis/objective of the study clearly described?	1	1	1	1	4/4 100% Short
2. Are the outcomes to be measured clearly described in the introduction or in the methods section?	1	1	1	1	4/4 100% Short
3. Are the characteristics of the patients included in the study clearly described?	1	1	1	1	4/4 100% Short
5. Is the distribution of the main confounders in each group of individuals to be compared clearly described?	0	0	0	0	0/4 0% High
6. Are the main findings of the study clearly described?	1	1	1	1	4/4 100% Short
7. Does the study provide estimates of the random variability of the main findings data?	1	1	1	1	4/4 100% Short
9. Were the characteristics of the missing participants described?	1	1	0	0	2/4 50% Moderate
10. Were 95% confidence intervals and/or p-values reported for the main outcomes, except when the p-value was less than 0.001?	1	1	1	1	4/4 100% Short
11. Were the subjects invited to participate in the study representative of the entire population from which they were recruited?	1	1	0	1	3/4 75% Moderate
13. Were the staff, places, and facilities where patients were treated representative of the treatment most patients receive?		0	0	1	50% Moderate

16. If any of the results of the study were based on “data dredging”, was this made clear?	1	1	1	1	4/4 100% Short
17. In trials and cohort studies, do the analyzes adjust for different follow-up times, or in case-control studies, is the time between intervention and outcome the same for cases and controls?	1	1	1	1	4/4 100% Short
18. Were the statistical tests used to assess the main outcomes appropriate?	1	1	1	1	4/4 100% Short
20. Were the main outcome measures accurate (valid and reliable)?	1	1	1	1	4/4 100% Short
25. Was there an adequate adjustment of confounders in the analyzes from which the main findings were drawn?	0	0	0	0	0/4 0% High
26. Have patient losses in progress been taken into account?	1	0	1	0	2/4 50% Moderate
27. Is the study powerful enough to detect a clinically important effect when the p-value (“probability value”) for a difference that is due to chance is less than 5%?	1	1	0	1	3/4 75% Moderate
Total points (18 points)	15	13	11	13	
Methodological quality of each study	83.3% High	72.2% High	61.1% Moderate	72.2% High	

The values refer to the scores of the studies in certain domains (subscales) of the Downs and Black scale.

DISCUSSION

Summary of Evidence

To the best of our knowledge, this is the first study that systematically evaluated the knee extensors' electrical activation during the partial and deep squat exercises in individuals with strength training experience. Deep squat and partial squat showed similar knee extensor EMG activity. The different experimental designs (intervention or observational), biases in the participants' selection, sample size, and the familiarization with the exercise and protocol, used in the four studies, generated several methodological limitations that might explain the great variability in the activation results and, consequently, their divergence.

Studies evaluating acute effects with the same target population showed no differences in the knee extensors' activation between partial and deep squats^{5,15}. However, these studies were excluded from the current review for not meeting the eligibility criteria (studies of intervention), or because they had incomplete data (another population, such as sedentary and bodybuilders), thus preventing their qualitative analysis. As the methodological quality of the included studies was moderate to high, another explanation for the absence of difference in knee extensor activation between the two exercises may be related to the changes in neuromuscular requirements among the joints in the lower limb when going from a partial to a deep squat.

Our initial hypothesis was that a greater knee extensor activation would be necessary to sustain this greater knee flexion angle during deep squat, due to the knee extensors' reduced force production capacity. In the partial squat, the knee extensors have a mechanical advantage over the deep squat, as they are close to the optimal length or to the plateau of the force-length relation (i.e., between 60°-70° of knee flexion)^{22,23}. However, from 90° to 120° of knee flexion (i.e., deep squat) there is a reduction in their force generation capacity (i.e., a mechanical disadvantage) because the knee extensors are working on the descending limb of the force-length relationship, with a lower capacity for force production^{21,22}. This mechanical advantage (i.e., knee extensors close to the optimal length of force generation)^{22,23} suggests a reduced need for motor unit recruitment in the partial squats. However, during the deep squat, the knee

extensors' mechanical disadvantage probably determines the greater involvement of hip extensors and ankle plantar flexors, as well as the knee extensor lower activation.

There is evidence of greater activation of the gluteus maximus and plantar flexor muscles in the deep squat in addition to the knee extensors. Caterisano et al.¹¹ demonstrated that the EMG activity of the gluteus maximus muscle was significantly higher in the deep squat compared to the partial squat. Similarly, the plantar flexors also generated greater activation in the deep squat^{6,20}. This greater activation of the hip extensors and plantar flexors during the deep squat exercise may have reduced the demand for the knee extensor activation.

In the descending or eccentric phase of the deep squat, there is a synergistic action between the hip extensor muscles, knee extensors, and ankle plantar flexors. The hip extensors work in the ascending-descending phases of the force-length relationship, with an optimal angle of force production during hip flexion. In this position, the hip extensors are stretched and producing force at their greatest lengths. As the hip extensors shorten, their force production capacity decreases in the smallest lengths²². The plantar flexors work in the ascending limb of the force-length relationship, that is, the more stretched these muscles are, the higher is the force produced at greater lengths^{22,24}. Therefore, the higher activation of the hip extensors and plantar flexors and their higher active elongation during the eccentric action can generate the sensation of a greater effort of these synergistic muscles that are recruited to assist in the movement performance due to the abovementioned mechanical disadvantage of the knee extensors^{6,20}.

This greater force generated at longer lengths during deep squats can also activate with greater intensity the Golgi tendon organs, responsible for sending the central nervous system information about the level of muscle tension. Those higher levels of muscle tension (both active and passive in the eccentric phase) can increase the number and intensity of sensory stimuli sent to the central nervous system, which can produce a central perception of higher effort level¹. Therefore, in acute conditions, we can infer that, in the deep squat, hip extensors and plantar flexors assume the overload resulting from the mechanical disadvantage of the knee extensors, allowing them to produce the same activation levels they generated in the partial squat.

Another important limiting aspect to consider is that the studies varied in the way they analyzed the EMG signal, as they used both the mean and the peak activation values normalized to the MVC values (i.e., percentage values). Furthermore, two studies^{6,19} divided the squat movement into concentric and eccentric phases. However, the use of the combined analysis of the concentric and eccentric phases seems to be more suitable for comparisons between the proposed exercises, as it considers the full activation of the knee extensors during the entire ROM. Another aspect is that the total execution time for the partial and deep squat movements is different, being greater in the deeper than in the partial squat, which also brings some limitations to the analysis of the EMG signal and may contribute to the greater effort sensation in the deep squat.

Criticism has been reported for the use of surface EMG in dynamic conditions, as they are influenced by the non-stationarity of the EMG signal by the muscles' displacements under the electrodes fixed on the surface of the skin, and by changes in muscle architecture during dynamic repetitions^{8,9,10}. It is also important to recognize the existence of extrinsic and intrinsic limitations in the use of surface EMG that may interfere with the obtained results. Extrinsic limitations include the ability to control some sources of external factors, which can interfere with the capturing of the EMG signal, such as, for example, the ambient temperature, electrode placement, and skin preparation^{11,21}. The intrinsic factors are those that cannot be controlled, and involve the characteristics of motor units, body temperature, amount of subcutaneous fat and crosstalk (which is the interference produced by capturing the activity of other muscles close to the electrodes)^{11,21}.

Despite the assessment strategies used in the studies included in this review and their high methodological quality, care must be taken not to extrapolate the results from acute cross-sectional studies that used surface EMG to understand the effects of partial and deep squat exercises for possible chronic effects, such as studies related to strength gain and muscle hypertrophy with the use of these exercises. Surface EMG seems to be an excellent strategy for the analysis of muscle activation during strength training exercises such as the squat. In longitudinal studies, it may allow answering questions related to neural (e.g., increased motor unit recruitment, motor control) and muscular (e.g., gains in muscle mass and strength) adaptations, and future studies should evaluate the chronic effects of partial and deep squat exercises and their effects on the electrical activity and neuromuscular efficiency of the knee extensor muscles. In addition, future studies should evaluate, both acutely and chronically, the synergistic action of muscles acting at the hip, knee, and ankle joints during squatting exercises to assess possible changes at proximal (hip), local (knee) and distal (ankle) neuromuscular changes that may occur and that are important to both strength training and rehabilitation²⁵.

Strengths and limitations

Our study has several methodological strengths. We conducted a sensitive, comprehensive, and systematic bibliographical search with explicit eligibility criteria and reproducible, without language restriction, performed by two reviewers independently. The analysis of methodological quality of the included articles was also performed by two independent reviewers. Another important point was that we chose to use the adapted Downs and Black bias risk tool, which was designed to assess the quality of observational studies suggested by the Cochrane Collaboration.

However, a potential limitation of this review is the low number, and small sample sizes per comparison among the trials that were included, which prevented us to provide robust estimates of the effects of the assessments. In addition, the included studies were methodologically limited. None of the studies fully presented the items observed in the risk of bias assessment regarding confounding

factors (descriptions of loss to follow-up) and statistical power. Similarly, the low sample number and absence of sample size calculation of some studies, as well as the different protocols for carrying out the squats, indicate that we should be cautious when inferring the results for the target population. Another limitation was the focus on young men and women, healthy and experienced in strength training, which makes our results not applicable to other populations. In addition, the included studies did not perform assessments of both sexes, as they assessed separately men or women (2 studies with men and 2 studies with women). Therefore, we cannot say that their results apply to both sexes.

Due to the variability of the EMG values in the results, it was not possible to perform a meta-analysis to quantitatively express the obtained results. This method could provide more reliable estimates of the effectiveness of the evaluations than individual studies because it has greater statistical power. Consequently, due to not performing a meta-analysis, it was also not possible to assess the quality of the evidence through the GRADE (The Grading of Recommendations Assessment, Development and Evaluation Approach). The low number of studies included in our review also generates limited information in acute conditions of electrical activation of the two forms of squat. Therefore, we cannot infer that any estimate of the effect is uncertain or not, nor that new studies will likely have a more important impact on our confidence to estimate the effect.

The results of the present review constitute an aim at adequating parameters for the selection of exercises in training and rehabilitation, according to the level of muscle activation. However, it is important that trainers and clinical professionals search for knowledge to complement the currently described information. This is necessary for ensuring tailored recommendations of squats according to the client's needs.

Furthermore, the experimental designs of future studies should be carried out to evaluate the electrical activation by specific joint ROMs or bands of angles. The evaluation of EMG signals by different joint ROM ranges will make it possible to control the muscle lengths at which the muscles are being recruited. Studies with fatigue protocols involving both knee extensors and the synergistic muscles in the squat movement (hip extensors and plantar flexors) should also be included in future studies, as they will allow us to better understand possible changes in the electrical activation of synergistic muscles in different types of squat exercises.

Although careful interpretation should be taken due to the lack of robustness of the findings (due to the number of included studies), we believe that results of this systematic review may support the prescriptions and selections of exercises in different sports modalities according to the level of muscle activation and based on the athlete's needs (e.g., aesthetics, performance, health).

CONCLUSION

This systematic review, based on the PRISMA recommendations and MOOSE, with studies with moderate and high methodological quality, showed that electrical activation of the knee extensor muscles does not differ between partial and deep squats. Our results support the relevance of trainers and clinical professionals in selecting and using squat variations that best suit their individual client/patient needs. Due to the low number of studies, the results should be interpreted with caution, and new evidence should be obtained to provide more robust evidence of the present findings.

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