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Systematic Review

Effects of the back-squat exercise on lower limb myoelectric activity in trained men: a systematic review

Efeitos do exercício agachamento por trás na atividade mioelétrica de membros inferiores em homens treinados: uma revisão sistemática

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ABSTRACT
Aim: The aim of this study was to describe the effects of the back-squat exercise on the lower limb myoelectric activity in trained men. **Methods:** We conducted a systematic review following the recommendations of PRISMA. Medline (PubMed), Scielo, Scopus, SPORTDiscus, and Lilacs databases were searched. The search terms included electromyography, exercise, resistance training, and squat. We included experimental studies that described the back-squat exercise using surface electromyography (EMG) in men experienced in resistance training and back squat exercise at angles from 60º to 90º. **Results:** Eight studies met the inclusion criteria. The interventions of the included studies ranged from 2 to 7 days. The protocols demonstrated to improve the neuromuscular system and to provide greater acquisition of strength in the muscles involved in performing the back squat exercise ($p < 0.05$). Thirty-seven muscles were analyzed, with a predominance of the vastus lateralis, vastus medialis, gluteus maximus, and rectus femoris muscles. **Conclusion:** The studies investigated in this review showed that the back-squat exercise at angles from 60º to 90º increased the lower limb myoelectric activity recorded in loads of 30% and 100% of 1RM in men experienced in resistance training. However, more studies with higher methodological quality are needed in the analysis of the squat exercise to reduce the risk of bias.

Keywords: electromyography; squat exercise; resistance training; muscle strength.

RESUMO
Objetivo: O objetivo deste estudo foi descrever os efeitos do exercício de agachamento por trás sobre a atividade mioelétrica de membros inferiores em homens treinados. **Métodos:** Foi realizada uma revisão sistemática seguindo as recomendações do PRISMA. Foram pesquisadas as bases de dados Medline (Pubmed), Scielo, Scopus, SPORTDiscus e Lilacs. Os termos de pesquisa incluíram eletromiografia, exercício, treinamento de resistência e agachamento. Foram incluídos estudos experimentais que descreveram o exercício de agachamento por trás por meio da eletromiografia de superfície (EMG) em homens com experiência em treinamento resistido (TR) e exercício de agachamento por trás em ângulos de 60º a 90º. **Resultados:** Oito estudos preencheram os critérios de inclusão. As intervenções dos estudos incluídos variaram de 2 a 7 dias. Os protocolos demonstraram melhorar o sistema neuromuscular e proporcionar maior aquisição de força nos músculos envolvidos na realização do exercício de agachamento por trás ($p < 0,05$). Foram analisados 37 músculos, com predomínio dos músculos vasto lateral, vasto medial, glúteo máximo e reto femoral. **Conclusão:** Os estudos investigados nesta revisão mostraram que o exercício de agachamento por trás em ângulos de 60º a 90º aumentou a atividade mioelétrica de membros inferiores registrada em cargas de 30% e 100% de 1RM em homens experientes em TR. Porém, mais estudos com maior qualidade metodológica são necessários na análise do exercício de agachamento para reduzir o risco de viés.

Palavras-chave: eletromiografia; exercício de agachamento; treinamento de resistência; força muscular.

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Introduction

The squat exercise is one of the most used exercises in the prescription of resistance training (RT) and physical fitness. This exercise is also applied to prescriptions intended for clinical treatments. This applicability is due to the capacity of the squat exercise for strengthening the muscles of the lower limbs in the treatment of ligament injuries, patellofemoral dysfunction, and ankle instability [1-3].

The squat exercise has also been part of the sports training programs as it presents biomechanical and neuromuscular similarities to a wide range of athletic movements [4]. In this way, it has been included as the central exercise of many sports routines. Once established the biomechanical model, added to an anatomical analysis for its execution, the squat exercise is used to improve physical fitness, with associated benefits that are not limited to the athletic population [5].

Additionally, many activities of daily living (ADL) require the coordinated and simultaneous interaction of various muscle groups. Thus, the squat exercise can be used to improve muscle strength of the lower limbs, favoring the performance of the ADL. This stems from the ability to recruit multiple muscle groups in a single movement [6].

From this perspective, the study of muscles may be important in providing information on the control of voluntary movements, in the analysis of reflexes and measurement of muscle groups involved in the squat exercise [7]. This exercise activates about 200 muscles [6] and can be performed with a variety of depths, usually measured by the degree of the knee flexion, such as partial (knee at 40º angle), half (60, 70 to 90º), and full squat exercise (greater than 90º) [8].

The myoelectric activity of human muscles can be measured by surface electromyography (EMG). The EMG allows measuring the change in membrane potential, that is, how the action potentials are transmitted along with the muscle fiber according to the exercise stimulus performed [9]. Therefore, this systematic review aimed to describe the effects of the back squat exercise on the myoelectric activity of the lower limbs in trained men.

Methods

This systematic review followed the recommendations of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [10] and was registered on the International Prospective Register of Systematic Reviews (PROSPERO), as number CRD42018082308.

Study eligibility and inclusion criteria

We included experimental studies using RT with acute intervention that evaluated the back squat exercise using EMG in men with experience in RT and squat exercise at 60º to 90º angles. Review studies, studies with individuals who presented

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some muscle injury or physical limitations, or written in another language other than English, Portuguese, or Spanish were excluded from this study review.

Search strategy

A search was performed without filters in the Medline (via PubMed), SciELO, Scopus, SPORTDiscus, and Lilacs (via BVS) databases, in May 2020, using the terms "electromyography", "exercise", "resistance training" and their respective synonyms, and "squat". These descriptors and their synonyms were appropriately combined using the logical operators [AND] between descriptors and [OR] between synonyms (Appendix 1). Although the term "squat" was not identified on the Health Sciences Descriptors (DeCS) and Medical Subject Headings (MeSH), it was inserted in the main descriptors as a search strategy because it appeared in some previous studies on the theme. The reference lists and other sources were researched to find further studies.

After the references were extracted using the search terms, they were exported to a shared Mendeley library. Two authors completed the research, the removal of duplicates, the analysis of titles and abstracts, and the screening of complete articles. Any divergences in the analysis were sent to a third author. Then, we read the full version of the articles that met the eligibility criteria of the present study.

Bias analysis

The ROBINS-I (Risk Of Bias In Non-randomised Studies - of Interventions) tool was used to assess the risk of bias in the studies included in this systematic review [11]. The studies were classified as "selection bias", "performance bias", "detection bias", "monitoring bias", "report bias", "lack of data bias", and "bias" in result selection reported, with the answers "yes", "probably yes", "probably not", and "no". Two independent and experienced evaluators analyzed the risk of bias in the included studies. Disagreements were assessed by a third researcher.

Data collection process

The following data were extracted from the selected studies: country, number of participants in each group, age, body mass, height (Table I), intervention protocol, muscles tested, methodologies, tests used for data analysis, and main results (Table II).

Results

In total, 350 studies were found following the proposed research methodology. After using the selection criteria, eight articles were included in this review (Figure 1).

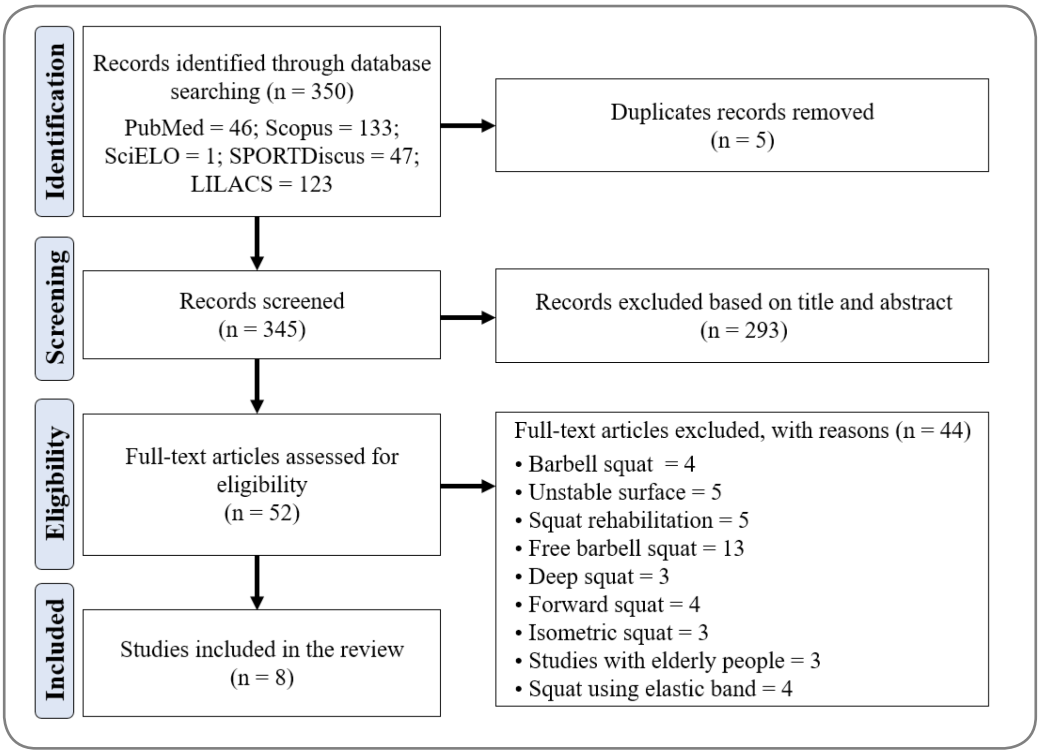

Figure 1 - Flow chart of the selected articles

Table I presents the descriptive characteristics of the studies included in this review. When analyzing the eight studies [12–19] in Table I, it was observed a population of 107 trained men (mean age: 25.13 ± 1.93 years; body mass: 82.62 ± 2.05 kg; height: 1.74 ± 0.03 m).

Table I- Descriptive characteristics of the studies included in the review

Study	Study country	Kind of sample	Study sample	Sample characteristics		
				Age (years)	Height (m)	BM (kg)
Clark *et al.* [12]	Ireland	Stratified	10	26.6± 8.4	1.7 ± 0.3	86.1 ± 7.8
Fletcher and Bagley [13]	USA	Stratified	14	21.7 ± 2.6	1.79 ± 0.07	83.2 ± 14.1
Gomes *et al.* [14]	USA	Stratified	14	24 ± 4	1.76 ± 6	81 ± 11
Mina *et al.* [15]	USA	Stratified	16	26.0± 7.8	1.7 ± 0.2	82.6 ± 12.7
Mina *et al.* [16]	France	Stratified	16	26 ± 7.8	1.73 ± 0.2	82.6 ± 12.7
Silva *et al.* [17]	Brazil	Stratified	15	26.5± 6.9	1.74	80.8 ± 5.2
Silva *et al.* [18]	Brazil	Aleatory	10	26 ± 5	1.73 ± 0.05	—
Yavuz *et al.* [19]	Turquia	Not informed	12	21.2 ± 1.9	—	—

USA = United States of America; BM = Body mass

Table II presents the methodological characteristics and the results regarding the resting conditions in the imposition of the maximum load in all studies, including the muscle strength test used, the muscle group evaluated and the EMG results before and after the intervention. Thirty-seven muscles were analyzed, with a predominance in the analysis of the rectus femoris (RF), vastus lateralis (LV), vastus medialis (VM), gluteus maximus (GM), and rectus femoris muscle.

Table II - Methods and outcomes of the studies included in this review

Study	EMG result (% - ±) Pre- vs. post- intervention		Inter-vention profile (days)	Muscles analyzed	p-value	Used test	Training loads (kg)
Clark *et al.* [12]	RA = 21.1±14.7	↑90.3 ± 65.0	3	RA	p<0.001		
	LS = 16.2±18.4	↑66.7 ± 48.41		LS	p<0.001		
	EO = 26.1±26.3	↑54.5± 15.3		EO	p<0.001	1RM	393.4±28.20
	ULES = 20.7±19.3	↑108.6 ± 10.4		ECLS	p<0.001		
	VL= 10.4±8.0	↑54.8 ± 39.0		VL	p<0.001		
Fletcher and Bagley [13]	EC= 107.8 ± 38.1	↑113.5 ± 37.1	7	ES, GM,	p<0.05	1RM	397.5±7.94
	EC= 119.5 ± 39.5	↑134.1 ± 55.4		ST, BF	p<0.001		
Gomes *et al.* [14]	GM= 12%	↑19.7%	5	GM	p<0.001	1RM	107±30
	VL= 34.4	↑45.6%		VL	p<0.001		
Mina *et al.* [15]	ST= 77.4 6 9.7	↑137.6 ± 26.8	2	RF, VM, ST	p<0.05	1RM	282.7±7.42
	QL = 95.9 ± 3.5	↑100.8 ± 4.6		VL, QL	p<0.05		
Mina *et al.* [16]	ST= 76.0 ± 11.2	↑75.7 ± 18.0	3	VM, VL,	p<0.05	1RM	280.6±5.94
	QL= 78.6 ± 3.5	↓70.5 ± 6.3		RF, ST			
Silva *et al.* [17]	GM= 1.0	↑29.37%	2	GM	p=0.004		
	BF = 0.22	↑11.78%		BF	p=0.009	10RM	163.4±15.27
	LS = 0.27	↑10.85%		SL	p=0.031		
Silva *et al.* [18]	VM = 103.37	↑110.3%	4	VM	p<0.05		
	VL = 84.7	↑102.14%		VL	p<0.05	8-12RM	297.35±12.40
	RF = 85.58	↑102.54 %		RF	p<0.05		
	BF = 92.19	↑120.93%		BF	p<0.05		
Yavuz *et al.* [19]	VM= 72 ± 57.6	↑76.4 ± 61.8	2	RF, VL, VM,	p<0.05	1RM	270.4±21.50
	GM= 30 ± 17.9	↑50.2 ± 30.8		EC, GM, BF,			
				ST			

EMG= electromyography; RM= repetition maximum; RA= rectus abdominis; EO= external oblique; ULES= upper lumbar erector spinae; LS= lumbar sacral; ES= erector spinae; VM= vastus medialis; VL= vastus lateralis; RF= rectus femoris; ST= semitendinosus; BF= biceps femoris; SL= soleus; GM= gluteus maximus; LS= Lumbar Spine; ↑ increase, ↓ decrease.

Table III shows the studies' risk of bias through the ROBINS-I tool. Regarding the studies analyzed using the ROBINS-I tool, 70% [13,15,16,17,19] were considered with critical risk of bias, while only 30% [12,14,18] were considered with moderate risk of bias.

Table III - Analysis of risk of bias using the ROBINS-I tool

Study	1	2	3	4	5	6	7	Total
Clark *et al.* [12]	P. No	No	P. Yes	P. Yes	Yes	P. Yes	P. Yes	5
Fletcher and Bagley [13]	P. No	P. Yes	Yes	Yes	Yes	P. Yes	Yes	6
Gomes *et al.* [14]	P. No	No	P. No	P. Yes	Yes	P. Yes	P. Yes	4
Mina *et al.* [15]	P. No	P. Yes	P. Yes	P. Yes	P. Yes	P. Yes	P. Yes	6
Mina *et al.* [16]	P. No	No	Yes	Yes	Yes	P. Yes	Yes	5
Silva *et al.* [17]	P. No	P. Yes	P. Yes	P. No	P. Yes	P. Yes	P. Yes	5
Silva *et al.* [18]	P. No	Yes	Yes	Yes	Yes	Yes	No	5
Yavuz *et al.* [19]	P. Yes	Yes	Yes	Yes	P. Yes	Yes	Yes	6

P = Probably; 1 = Selection bias; 2 = Performance bias; 3 = Detection bias; 4 = Monitoring bias; 5 = Reporting bias; 6 = Lack of data bias; 7 = Bias in the selection of the reported result

Discussion

The purpose of this systematic review was to describe the effects of the back squat exercise on the lower limb myoelectric activity in trained men. The analysis of the eight cross-sectional studies [12-19] showed greater muscle myoelectric activity during different squat protocols, but these do not represent a greater strength gain promoted by the type of exercise ($p < 0.05$).

The mean EMG of the RMS signals (20 Hz to 392 Hz) varied for the muscles analyzed (VM, VL, and GM) during the rising phase of the lift with each load during the repetition maximum (RM) tests of the back squat exercise. However, the findings of these experimental studies should be interpreted with caution, as they were classified as uncertain risk of bias (Table III).

As for the interventions, five studies used the RT through free weights with bars and washers [12-15,19], two [16,17] used barbell and the Smith Machine, and one study [18] did not describe the device used. Furthermore, two of these studies [12,14] performed the RM tests in the back-squat exercise, adding the knee pad. One of these studies [18] performed the 1RM test with loads of 80%, 90%, and 100%, using the EMG in the back squat exercise. However, general muscle myoelectric activities amplified with increasing loads, but significant increases in EMG signals were observed only in the vastus medialis (VM) and gluteus maximus (GM) muscles with 90% and 100% of 1RM loads. Likewise, Silva *et al.* [18] when submitted the sample to the squat exercise, observed an increase in the EMG activity of the GM and VM with increasing loads of 60% to 90% of 1RM.

McBride *et al.* [20] reported the use of heavy loads of 70% to 90% of 1RM to analyze the effect of instability and stability of the back squat exercise. The results showed a significant increase in the level of the EMG signal in the muscular activity of the vastus lateralis (VL), biceps femoris (BF), and erector of the spine, with the load of 90% of 1RM in the stable back squat exercise. On the other hand, Contreras *et al.* [21] and Aagaard *et al.* [22] compared the mean and peak of the EMG amplitude in the back squat exercises in an estimate of 10RM and found no significant differences in the EMG signal in the GM, BF, and VL muscles between the squats. The discrepancy between the findings of these studies may be due to the samples having experience in RT (>3 years). This may suggest a better strategy of muscle recruitment in the frequency of myoelectric activity during the execution of the back squat exercise used in different percentages of loads and RM [23].

This way, RT with different percentages of repetition maximum (% of 1RM) is used to improve different muscle properties, such as increased maximum strength, explosive strength, and hypertrophy [24]. Additionally, heavy loads (> 80% of 1RM) were used to recruit high threshold fast contraction motor units, according to the size of the muscle fiber, while smaller loads (60% of 1RM) are used to maintain the specificity of the training speed and improve the mechanical power [25]. Loads with different % of 1RM result in different neuromuscular and kinematic adaptations in the eccentric phase of the squat exercise [26].

Hence, the squat exercise is one of the most used exercises in many training protocols due to its applicability and functionality in sports and daily activities. Squat variations (example: back, front, Bulgarian, Sumo, and sink) are applied to physical conditioning, strength training, and physiotherapeutic rehabilitation [27]. Due to biomechanics and neuromuscular similarities to a range of athletic movements, squat is an essential exercise in many sports routines [28].

Thus, the squat aims to train the thigh muscles, the knee extensors (example: rectus femoris, vastus lateralis and vastus medialis), and strengthen the hip extensors (example: gluteus maximus, biceps femoris, and semitendinosus). Moreover, this exercise can develop muscle strength in the lower back, to perform basic skills required in sports and daily activities [29].

It is worth noting that, as the locomotor system adapts to an RT program, the individual must continue to undergo new percentages of load to continue to increase strength and muscle mass by gradually increasing the load and the number of sets or training frequency [30]. These variables are used to maintain the specificity of the speed execution of the squat exercise and improve mechanical power, strength and muscle hypertrophy [31].

All interventions with RT from the experimental studies analyzed in this systematic review are in accordance with the American College of Sports Medicine (ACSM) guidelines [32] for individuals experienced in RT, which includes changes in training loads (<80% of 1RM) to induce acute metabolic, hormonal, neural changes and cardiovascular responses to RT. Also, the 1RM test has been used as a gold standard in determining maximum dynamic strength and uses percentage values of maximum strength to determine training zones [33].

This systematic review has some limitations that should be highlighted. First, the samples were composed only of trained men and did not include women experienced in RT. Therefore, the results cannot be generalized to other populations. However, we opted for the exclusivity of men in the sample, as they tend to have greater body mass and muscle strength than women, due to the higher levels of anabolic hormones. In addition, there is a risk of interference of the muscles close to those analyzed using EMG, which would generate inaccurate edits. Hence, none of the studies was an analysis of the different moments of the myoelectric signal presented in the concentric and eccentric phases of the back squat exercise with different loads.

Conclusion

The studies analyzed in the present systematic review showed that the back-squat exercise at angles from 60º to 90º increased the lower limb myoelectric activity recorded in loads of 30% and 100% of 1RM in men experienced in RT. Nonetheless, it is suggested more studies with higher methodological quality in the analysis of the squat exercise to reduce the risk of bias.

Potential conflict of interest
No conflicts of interest with potential for this article have been reported.

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There were no external sources of funding for this study.

Academic link
This study is linked to the thesis of doctoral student Aguiar RS, from the Postgraduate Program in Exercise and Sports Sciences at the Rio de Janeiro State University.

Authors' contributions
Conception and design of the research: Aguiar RS, Castro JBP, Nunes RAM, Vale RGS, Scartoni FR; **Analysis and interpretation of data:** Aguiar RS, Castro JBP, Santos AOB, Silva GCPSM; **Statistical analysis:** Not applicable; **Obtaining financing:** Not applicable; **Writing of the manuscript:** Aguiar RS, Castro JBP; **Critical review of the manuscript for important intellectual content:** Aguiar RS, Castro JBP, Vale RGS.

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Appendix 1 - Searches adopted in the present study.

Database	Search phrase	Electronic address
Scielo	Eletromiografia e exercício e treinamento de resistência e agachamento	https://scielo.org/
Scopus	TÍTULO-ABS-KEY (*eletromyografia) E TITLE-ABS-KEY (*exercício) E TITLE--ABS-KEY (*resistência e treinamento) E TITLE-ABS-KEY (*agachamento) E (LIMIT-TO (DOCTYPE,"ar"))	https://www.elsevier.com/solutions/scopus
Lilacs (BVS)	Eletromiografia e exercício e treinamento de resistência e agachamento	https://www.lilacsbases.bireme.br
SPORTDiscus	Eletromiografia e exercício e treinamento de resistência e agachamento	https://www.ebsco.com
Medline (PubMed)	(((((((((Electromyography[Title/Abstract]) OR (Electromyographies [Title/Abstract])) OR (Surface Electromyography[Title/Abstract])) OR (Electromyographies, Surface[Title/Abstract])) OR (Electromyography, Surface[Title/Abstract])) OR (Surface Electromyographies [Title/Abstract])) OR (Electromyogram[Title/Abstract])) OR (Electromyograms[Title/Abstract])) AND ((((((((((((((((Exercise[Title/Abstract]) OR (Exercises[Title/Abstract])) OR (Physical Activity[Title/Abstract])) OR (Activities, Physical[Title/Abstract])) OR (Activity, Physical[Title/Abstract])) OR (Physical Activities[Title/Abstract])) OR (Exercise, Physical[Title/Abstract])) OR (Exercises, Physical[Title/Abstract])) OR (Physical Exercise[Title/Abstract])) OR (Physical Exercises[Title/Abstract])) OR (Acute Exercise[Title/Abstract])) OR (Acute Exercises[Title/Abstract])) OR (Exercise, Acute[Title/Abstract])) OR (Exercises, Acute[Title/Abstract])) OR (Exercise Training[Title/Abstract])) OR (Exercise Trainings[Title/Abstract])) OR (Training, Exercise[Title/Abstract])) OR (Trainings, Exercise[Title/Abstract]))) AND ((((((((((((((((((((((Resistance Training[Title/Abstract]) OR (Training, Resistance[Title/Abstract])) OR (Strength Training[Title/Abstract])) OR (Training, Strength[Title/Abstract])) OR (Weight-Lifting Strengthening Program[Title/Abstract])) OR (Strengthening Program, Weight-Lifting[Title/Abstract])) OR (Strengthening Programs, Weight-Lifting[Title/Abstract])) OR (Weight Lifting Strengthening Program[Title/Abstract])) OR (Weight-Lifting Strengthening Programs[Title/Abstract])) OR (Weight-Lifting Exercise Program[Title/Abstract])) OR (Exercise Program, Weight-Lifting[Title/Abstract])) OR (Exercise Programs, Weight-Lifting[Title/Abstract])) OR (Weight Lifting Exercise Program[Title/Abstract])) OR (Weight-Lifting Exercise Programs[Title/Abstract])) OR (Weight-Bearing Strengthening Program[Title/Abstract])) OR (Strengthening Program, Weight-Bearing[Title/Abstract])) OR (Strengthening Programs, Weight-Bearing[Title/Abstract])) OR (Weight Bearing Strengthening Program[Title/Abstract])) OR (Weight-Bearing Strengthening Programs[Title/Abstract])) OR (Weight-Bearing Exercise Program[Title/Abstract])) OR (Exercise Program, Weight-Bearing[Title/Abstract])) OR (Exercise Programs, Weight-Bearing[Title/Abstract])) OR (Weight Bearing Exercise Program[Title/Abstract])) OR (Weight-Bearing Exercise Programs[Title/Abstract]))) AND (Squat[Title/Abstract])	https://www.ncbi.nlm.nih.gov