NEUROMUSCULAR AND FUNCTIONAL RESPONSES TO CONCENTRIC AND ECCENTRIC STRENGTH TRAINING IN OLDER ADULTS: A SYSTEMATIC REVIEW

Eliane C. Guadagnin[1,2], Karine J.V. Stoelben[1], Felipe P. Carpes[1], and Marco A. Vaz[2]

[1]Applied Neuromechanics Research Group, Laboratory of Neuromechanics,
Federal University of Pampa, Uruguaiana, RS, Brazil
[2]Biomechanics and Kinesiology Research Group, Exercise Research Laboratory,
School of Physical Education, Physical Therapy and Dance,
Federal University of Rio Grande do Sul, Porto Alegre, RS, Brazil

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Abstract:

The type of muscle action is important when designing exercise interventions for older individuals and may result in different effects. In this study we performed a systematic review of controlled trials comparing the effects of concentric and eccentric resistance training, performed on isokinetic dynamometers, on lower extremity muscular and functional performance in older adults (CDR42017075316). Six databases (Pubmed, CINAHL, SPORTDiscus, PEDro, Cochrane Central, and Embase) were searched. Outcomes of interest concerned neuromuscular and functional performance. Trials should consider 65 years or older individuals participating in concentric and/or eccentric training on isokinetic dynamometers, at least twice a week, during at least four weeks. Results should be compared to a control group or between different contraction types. A qualitative analysis of data was done. Quality assessment considered the Cochrane Risk of Bias Tool. The initial search returned 10376 studies and four trials were considered for inclusion. Three trials compared the effects of concentric training with the ones of control groups, and one compared the effects of concentric with the ones of eccentric training. All trials focused on knee extensor and flexor muscles, and one also focused on ankle dorsiflexors and plantarflexors. Training programs included three sessions/week lasting 8-12 weeks. Concentric training improved strength, power, and muscle antagonist coactivation compared to the control. Concentric and eccentric training improved knee isometric, concentric and eccentric strength and scores on self-paced step test, with no effect on gait speed. They did not consider muscle structural parameters. The findings of beneficial effects of isokinetic concentric and eccentric resistance training on muscle strength and power in older adults were consistent. However, there is a lack of trials addressing the effects of isokinetic strength training on muscle structure and functionality.

Key words: *aged, aging, resistance training, lower extremity, physical examination*

Introduction

Life expectancy at 60 years of age is gradually increasing, changing from 18.8 years to 20.5 years from 2000 to 2016 (WHO, 2018). Aging is accompanied by several adaptations in the musculoskeletal system structure and function. These changes include reduced muscle mass and strength (Kamel, 2003; Nilwik, et al., 2013), which might be associated with sarcopenia and dynapenia (Clark & Manini, 2008), resulting in impaired functionality and increasing the risk of falls (Kamel, 2003).

The importance of muscle strength for maintenance of the elderly's functionality is recognized in the literature (Schaap, Koster, & Visser, 2013). Losses in muscle mass have the onset at the age of 25 years, and gradually increase as the age advances (Lexell, Taylor, & Sjostrom, 1988). Around the 4th decade of life, muscle strength reduction initiates (Akima, et al., 2001; Amaral, et al., 2014; Trudelle-Jackson, Ferro, & Morrow, 2011), and by the age of 80 years an individual may lose up to 40% of muscle mass in comparison to a young adult (Lexell, et al., 1988). These losses result from reduced size (hypotrophy) of type II muscle fibers (Nilwik, et al., 2013), and, to a lesser extent, from reduced number (atrophy) of both fiber types I and II (Lexell, et al., 1988). However, there are other neuromuscular parameters that determine musculoskeletal system adaptations to aging, which include a decline in the neuromuscular activation capacity, an increased antagonist co-contraction (Arnold & Bautmans, 2014), and alterations in muscle architecture (Narici, Maganaris, Reeves, & Capodaglio, 2003). Taken together, these adaptations limit functional tasks' performance, including those required for daily life independence.

Many types of training programs lead to successful improvements of muscular parameters (e.g. strength, power, echo intensity, cross-sectional area) and functionality (e.g. gait speed, sit-to-stand) (Hortobagyi, et al., 2015; Labata-Lezaun, et al., 2023; Lopez, et al., 2022) in older adults. However, it is still not clear which muscular parameters are related to the functional improvements (Beijersbergen, Granacher, Vandervoort, DeVita, & Hortobagyi, 2013). One of the most advocated strategies to slow down or reverse sarcopenia, and to improve elderly's functionality and independence based on physical exercise, is the resistance training including concentric and eccentric muscle actions (Guizelini, de Aguiar, Denadai, Caputo, & Greco, 2018; Kamel, 2003; Lopez, et al., 2017). Concentric training increases the pennation angle of trained muscles compared to eccentric training (Reeves, Maganaris, Longo, & Narici, 2009). Eccentric training increases fascicle length more than concentric training (Reeves, et al., 2009). Therefore, both training modalities can produce different effects on strength, muscle structure, and functionality (Katsura, Takeda, Hara, Takahashi, & Nosaka, 2019). On the other hand, both types of muscle contractions are required during the performance of daily life tasks, and, consequently, are functionally important. Activities like rising from a chair, climbing stairs, and walking uphill require mainly concentric actions from the hip and knee extensors. Eccentric actions are particularly required when sitting down on a chair, stair descending, and downhill walking/running.

Exercise training for one or more muscle groups can improve strength and functionality (Lee & Park, 2013; Symons, Vandervoort, Rice, Overend, & Marsh, 2005; Tracy, et al., 1999; Yoshiko & Watanabe, 2021). Strength, power, and muscle structural characteristics of different muscles are related to the functionality of older individuals (Rech, et al., 2014; Silder, Heiderscheit, & Thelen, 2008; Spink, et al., 2011). Thus, one can expect that improving these muscular parameters from one or more muscles can lead to gains in functionality. However, it is still unclear if different training configurations or modalities can generate specific functionality gains in older individuals. Therefore, it is important to systematically investigate whether concentric and eccentric strength training programs generate different improvements in different functional tasks.

Strength exercises can be performed on isokinetic dynamometers, with body weight-bearing exercises, and using traditional weight-lifting machines. Among these modalities, the isokinetic dynamometer training allows for strict load control (Kuruganti, Parker, Rickards, & Tingley, 2006), with the exercise being performed at constant angular velocity (Hislop & Perrine, 1967) and the possibility to monitor performance outcomes related to muscle strength such as the peak torque. Force production is dependent on contraction velocity, and, during body weight-bearing exercises and traditional weight-lifting machine exercises, angular velocity is not constant along the total joint range of motion. This change in angular velocity throughout the total range of motion reduces the mechanical load to the muscle (Malliou, et al., 2003) as well as underestimates its true capacity to generate force during both concentric and eccentric phases (Reeves, et al., 2009). Therefore, isokinetic strength exercises allow for a maximal effort from the target muscles through the entire joint range of motion and dynamic contraction modalities, thereby generating better skeletal muscle adaptations in older adults that might produce greater functional gains or smaller functional losses due to the natural aging process.

When designing exercise interventions for the elderly, it is important to have clear information regarding what type of muscle action may result in larger strength gains and larger effects on neuromuscular and functional performance. However, while previous studies have established the benefits of resistance training, differences between training programs based on concentric and eccentric actions remain unclear, independent if administrated isolated or combined. Thus, the aim of the present study was to perform a systematic review of controlled trials that compared the effects of concentric and eccentric resistance training on the lower extremity muscular and functional performance in older adults. The two training modalities could be performed either isolated or in combination, but only on isokinetic dynamometers.

Methods

This is a systematic review of controlled trials following the PRISMA Statement recommendations and registered in the International Prospective Register of Systematic Reviews – PROSPERO (CRD42017075316, available at https://www.crd.york.ac.uk/prospero).

Search strategy

Controlled trials, indexed in Medline (via Pubmed), CINAHL, SPORTDiscus, PEDro, Cochrane Central, and Embase, published until August 13th 2022, were searched. Reference lists from the studies included in this review were also searched to find other potential studies to be included.

Mesh terms, Emtree terms, and keywords related to the subject of interest (older individuals, strength training, and lower limbs) and the outcomes of interest (strength, rate of torque development, muscle activation, pennation angle, fascicle length, muscle thickness, echo intensity, and functional tests) were utilized combined with the Boolean operators "AND" and "OR". The complete description of the search strategy used in Medline via Pubmed database is available in Table 1. Searches in the remaining databases were adapted to the databases criteria and are available upon request.

Eligibility criteria

To be included, the controlled trials should address the effects of concentric or eccentric (either isolated or combined) training for the lower limbs and compare outcomes between different trainings and/or with a control group. Participants should be elderly (men or women, 65 years old or more), without severe pathologies, community dwelling or residents in geriatric institutions.

The training should last at least four weeks, with a frequency of two or more sessions per week (at least eight sessions in total), performed on isokinetic dynamometer with the angular velocity control. To be included, a description of the training characteristics should be available in the manuscript. Studies

Table 1. Complete description of the search strategy used in Medline via Pubmed database

	Mesh Terms
Participants	(Aged OR Elderly OR Aging OR Senescence OR Biological Aging OR Aging, Biological OR Aged, 80 and over OR Oldest Old OR Nonagenarians OR Nonagenarian OR Octogenarians OR Octogenarian OR Centenarians OR Centenarian OR Ageing OR Older OR Old)
Training	(Resistance Training OR Training, Resistance OR Strength Training OR Training, Strength OR Weight-Lifting Strengthening Program OR Strengthening Program, Weight-Lifting OR Strengthening Programs, Weight-Lifting OR Weight Lifting Strengthening Program OR Weight-Lifting Strengthening Programs OR Weight-Lifting Exercise Program OR Exercise Program, Weight-Lifting OR Exercise Programs, Weight-Lifting OR Weight Lifting Exercise Program OR Weight-Lifting Exercise Programs OR Weight-Bearing Strengthening Program OR Strengthening Program, Weight-Bearing OR Strengthening Programs, Weight-Bearing OR Weight Bearing Strengthening Program OR Weight-Bearing Strengthening Programs OR Weight-Bearing Exercise Program OR Exercise Program, Weight-Bearing OR Exercise Programs, Weight-Bearing OR Weight Bearing Exercise Program OR Weight-Bearing Exercise Programs OR Eccentric OR Eccentric Training OR Eccentric Exercise OR Eccentric Contraction OR Concentric OR Concentric Training OR Concentric Exercise OR Concentric Contraction OR Eccentric OR Lengthening Contraction OR Negative Work OR Positive Work OR Shortening Contraction OR concentric eccentric OR eccentric concentric)
Lower extremity	(Lower Extremity OR Extremities, Lower OR Lower Extremities OR Lower Limb OR Limb, Lower OR Limbs, Lower OR Lower Limbs OR Membrum inferius OR Extremity, Lower OR Hip OR Hips OR Coxa OR Coxas OR Hip Joint OR Hip Joints OR Joint, Hip OR Joints, Hip OR Acetabulofemoral Joint OR Acetabulofemoral Joints OR Joint, Acetabulofemoral OR Joints, Acetabulofemoral OR Knee OR Knee Joint OR Joint, Knee OR Joints, Knee OR Knee Joints OR Superior Tibiofibular Joint OR Joint, Superior Tibiofibular OR Joints, Superior Tibiofibular OR Superior Tibiofibular Joints OR Tibiofibular Joint, Superior OR Tibiofibular Joints, Superior OR Ankle OR Ankles OR Regio tarsalis OR Tarsus OR Ankle Joint OR Ankle Joints OR Joint, Ankle OR Joints, Ankle OR Inferior Tibiofibular Joint OR Inferior Tibiofibular Joints OR Joint, Inferior Tibiofibular OR Joints, Inferior Tibiofibular OR Tibiofibular Joint, Inferior OR Tibiofibular Joints, Inferior OR Articulation talocruralis OR Tibiofibular Ankle Syndesmosis OR Ankle Syndesmoses, Tibiofibular OR Ankle Syndesmosis, Tibiofibular OR Syndesmoses, Tibiofibular Ankle OR Syndesmosis, Tibiofibular Ankle OR Tibiofibular Ankle Syndesmoses OR Tibiofibular Syndesmosis OR Syndesmoses, Tibiofibular OR Syndesmosis, Tibiofibular OR Tibiofibular Syndesmoses OR Ankle Syndesmosis OR Ankle Syndesmoses OR Syndesmoses, Ankle OR Syndesmosis, Ankle OR Thigh OR Thighs OR Leg OR Legs OR Foot OR Feet)
Outcomes	(Muscle Strength OR Strength, Muscle OR Torque OR Torques OR Walking Speed OR Speed, Walking OR Speeds, Walking OR Walking Speeds OR Gait Speed OR Gait Speeds OR Speed, Gait OR Speeds, Gait OR Walking Pace OR Pace, Walking OR Paces, Walking OR Walking Paces OR Postural Balance OR Balance, Postural OR Musculoskeletal Equilibrium OR Equilibrium, Musculoskeletal OR Postural Equilibrium OR Equilibrium, Postural OR force OR power OR rate of torque development OR rate of torque production OR rate of force production OR rate of force development OR muscle activation OR muscular activation OR pennation angle OR fascicle length OR muscle thickness OR echo intensity OR echo-intensity OR muscle quality OR muscular quality OR functionality OR functional OR mobility OR gait velocity OR timed up and go test OR timed up and go OR TUG OR TUG test OR sit to stand OR sit to stand test OR 30 second sit to stand test OR 30 second sit to stand OR sit-to-stand OR sit-to-stand test OR five times sit-to-stand OR five times sit-to-stand test OR five-repetition sit-to-stand OR five-times-sit-to-stand OR five-times-sit-to-stand test OR jump OR vertical jump OR balance OR Stair Climbing OR Climbing, Stair OR Stair Navigation OR Navigation, Stair OR 6 min walk test OR 6 min walking test OR 6-min-walk-test OR 6-min-walking-test OR 6 minutes walk test OR 6 minutes walking test OR 6-minutes-walk-test OR 6-minutes-walking-test OR six min walk test OR six min walking test OR six six-min-walk-test OR six-min-walking-test OR six minutes walk test OR six minutes walking test OR six-minutes-walk-test OR six-minutes-walking-test)

investigating at least one of the outcomes of interest were included in the study.

Non-randomized or non-controlled trials, studies including hospitalized individuals, and/or individuals with some pathologies were not included. Studies including participants performing other physical exercise type concomitantly to the training program were not included. Finally, only articles written in English, Spanish or Portuguese were considered.

Study selection

Results from each database were exported for further analysis of titles and abstracts by two independent raters. Duplicated studies were excluded. Titles and abstracts were analyzed to select potential studies to be included in the review, and to exclude manuscripts that did not fill the eligibility criteria. Studies, selected by at least one rater, were downloaded and the eligibility criteria were applied. Two independent raters performed full-text analyses, and discrepancies were solved by consensus.

Outcomes

The considered outcomes were the following: lower limb strength, rate of torque development, muscle activation, pennation angle, fascicle length, muscle thickness, echo intensity, and performance in functional tasks. Functional tasks were considered for the assessment of gait speed (determined for different distances), stair ascent (time to climb different number of stairs), stair descent (time to step down different number of stairs), sit-to-stand (number of repetitions in different times or time to perform a determined number of repetitions), timed up and go test (time to perform the test), balance (static balance, bipodal or unipodal, time to maintain the position or center of pressure displacement), vertical jump (jump height) and 6-min walking test (distance walked in 6-min).

Quality assessment

Two independent reviewers evaluated the methodological quality of the included studies using the Cochrane Risk of Bias Tool, which considers the sequence generation, allocation concealment, blinding of participants and personnel, blinding of outcomes assessment, incomplete outcome data, selective outcome reporting, among other sources of bias. Each item was assessed as either a low risk of bias, high risk of bias or unclear in each of the included studies. Discrepancies were solved by consensus, and the methodological quality results were considered in the discussion.

Data extraction

Two reviewers used a standardized spreadsheet to extract data, and discrepancies were solved by consensus. Data extracted included publication info (author, year), participants' characteristics (number of participants and dropouts in each of the groups, sex, age, body mass, and body height), training characteristics (number of sessions, weekly frequency, exercises performed, volume, intensity, movement velocity, sets and repetitions), mean and standard deviation/standard error of outcome variables determined before and after training, and statistical results. If the study had more groups of study (other age group or training type), only the data about the groups of interest were extracted. When the data were presented in figures, raw data were requested by e-mail from the first author of the study in question.

Statistical analyses

Data analyses were planned to consider qualitative and quantitative approaches. However, the small number of included trials and the variety of outcomes described limited a quantitative assessment. Therefore, a qualitative analysis was performed considering the main characteristics, results, and limitations of each study in addition to the already mentioned quality assessment. Data described in the Results section regarding the effects of training are presented in the way each study informed them (e. g. mean, delta value, effect size).

Results

Yield

The initial search returned 10376 studies retrieved from the databases. Duplicates were removed and, after title and abstract analysis, 440 full texts were downloaded for analysis. After inclusion and exclusion criteria analysis, four trials fulfilled the eligibility criteria for inclusion in this systematic review of controlled trials. Figure 1 depicts the flowchart of the studies' search and inclusion.

Characteristics of the included trials

Table 2 shows the main characteristics of the participants and training programs. All trials considered older women (Laroche, Roy, Knight, & Dickie, 2008; Malliou, et al., 2003; Signorile, et al., 2002; Symons, et al., 2005), with two of these trials including only women (Laroche, et al., 2008; Signorile, et al., 2002). The mean age of the participants was 69.7 years. Three trials compared effects of a concentric training with a control group (Laroche, et al., 2008; Malliou, et al., 2003; Signorile, et al., 2002) and one trial compared groups performing a concentric versus an eccentric training (Symons, et al., 2005). All trials considered a weekly frequency of three sessions, with a total program duration

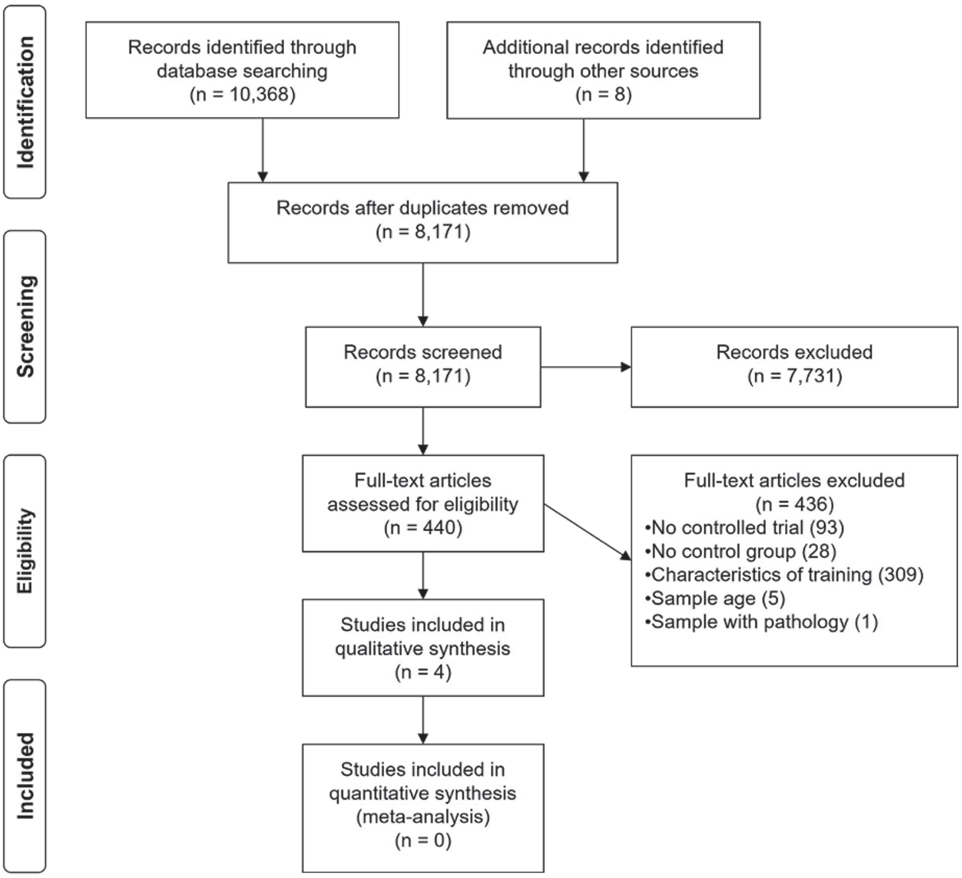

Figure 1. Flowchart of search and selection of the studies included in this systematic review.

ranging from eight to 12 weeks (Laroche, et al., 2008; Malliou, et al., 2003; Signorile, et al., 2002; Symons, et al., 2005), and were focused on knee extensor and knee flexor muscles. Ankle dorsiflexor and plantarflexor muscles were also considered in one study (Signorile, et al., 2002).

Training effects

Table 3 describes the studies' results and outcomes. Concentric training alone improved concentric strength, power, rate of torque development, and muscle activation in comparison to control groups (Laroche, et al., 2008; Malliou, et al., 2003; Signorile, et al., 2002). Functional parameters were not considered in these trials.

Concentric and eccentric trainings improved isometric, concentric and eccentric strength and results on the self-paced step test (stair test), without improvement in gait speed (Symons, et al., 2005). Muscle structural parameters (echo intensity, thick-

Table 2. Main characteristics of participants and training programs from the included trials

Participants				Characteristics of training							
Study	Groups	Age	Number/ Gender	Weekly frequency	Program duration	Muscular group	Lower limb	Intensity (%)	Velocity $(°\cdot s^{-1})$	Range of motion	Number of series x repetitions
Laroche et al., 2008	Control Concentric	73.7±4.6 71.3±6.3	12 F 12 F	3	8 weeks	knee extensors and flexors	L/R	100	45 and 200	90° to 180°	3x8 (each velocity)
Malliou et al., 2003	Control Concentric	69.9±4.3/65.7±4.3 69.7±2.2/68±5.1	10 M/F 12 M/F	3	10 weeks	knee extensors and flexors	NI	NI	150, 150 and 180	NI	3x12 (each velocity)
Signorile et al., 2002	Control Concentric HS Concentric LS	69.0±1.76 68.4±1.4 68.8±1.6	7 F 9 F 8 F	3	12 weeks	knee extensors and flexors; ankle plantarflexors and dorsiflexors	NI	NI	knee and ankle: HS: 270 and 180 LS: 60 and 60	NI	knee and ankle: HS: 10x1 and 8x1 LS: 6x1 and 6x1
Symons et al., 2005	Concentric Eccentric	71.8±3.1 70.5±5.2	10 M/F 9 M/F	3	12 weeks	knee extensors	L/R	100	NI	NI	3x10

Note. F: female; M: male; L: left; R: right; HS: high-speed training group; LS: low-speed training group; NI: not informed.

Table 3. Outcomes measured and results extracted from each included study as presented by the authors

Study	Outcome	Pre		Post		Effect of time		
Laroche et al., 2008		Control (mean±SE)	Concentric (mean±SE)	Control (mean±SE)	Concentric (mean±SE)	Control	Concentric	
	Knee extensor isometric peak torque (105°) (N·m·kg^{-1})	1.3±0.1	1.6±0.1	1.3±0.1	1.7±0.1	(~) p>0.05; ES=0.17	(↑) p=0.03; ES=0.25	
	Rate of torque development (105°) (N·m·s^{-1}·kg^{-1})	6.2±0.8	7.2±0.9	6.7±0.7	7.1±0.9	(~) p>0.05; ES=0.19	(~) p>0.05; ES=-0.02	
	Antagonist coactivation (%pEMG)	22.3±2.4	24.3±2.9	25.7±3.9	21.2±1.9	(~) p>0.05; ES=0.32	(↓) p=0.02; ES=-0.39	
	Onset EMG amplitude (%pEMG)	92.7±3.6	85.5±4.3	86.1±3.7	79.7±3.5	(~) p>0.05; ES=-0.54	(~) p>0.05; ES=-0.44	
	Rate of EMG rise (%pEMG)	1152.3±98.5	1079.4±95.6	1153.9±73.7	1001.1±76.6	(~) p>0.05; ES=0.01	(~) p>0.05; ES=-0.27	
Malliou et al., 2003		Control (mean±SD)	Concentric (mean±SD)	Control (mean±SD)	Concentric (mean±SD)	Control	Concentric	
	Knee extensors concentric peak torque 60°·s^{-1} (N·m)	109.6±10.8	106.3±12.2	107.9±9.2	118.3±12.8	(~) p>0.05	(↑) p<0.05	
	Knee extensors concentric peak torque 180°·s^{-1} (N·m)	66.3±6.8	68.4±9.2	65.9±5.2	81.3±5.8	(~) p>0.05	(↑) p<0.05	
Signorile et al., 2002		*Data were presented only as figures.		*Data were presented only as figures.		Control	HS	LS
	Knee extension average power 60°·s^{-1} (W)					(~) p>0.05	(~) p>0.05	(~) p>0.05
	Knee extension average power 180°·s^{-1} (W)					(~) p>0.05	(↑) Δ25.96±5.06 p=0.0007	(~) p>0.05
	Knee extension average power 300°·s^{-1} (W)					(~) p>0.05	(↑) Δ32.49±6.34 p=0.0004	(~) p>0.05
	Knee flexion average power 60°·s^{-1}s (W)					(~) p>0.05	(~) p>0.05	(~) p>0.05
	Knee flexion average power 180°·s^{-1} (W)					(~) p>0.05	(~) p>0.05	(~) p>0.05
	Knee flexion average power 300°·s^{-1} (W)					(~) p>0.05	(~) p>0.05	(~) p>0.05
	Ankle dorsiflexion average power 60°·s^{-1} (W)					(~) p>0.05	(↑) Δ2.51±0.55 p=0.0036	(↑) Δ3.50±0.36 p=0.0003
	Ankle dorsiflexion average power 180°·s^{-1} (W)					(~) p>0.05	(↑) Δ6.31±1.06 p=0.0001	(↑) Δ6.66±1.01 p=0.0001
	Ankle dorsiflexion average power 300°·s^{-1} (W)					(~) p>0.05	(↑) Δ5.65±0.82 p=0.0001	(↑) Δ7.60±0.65 p=0.0001
	Ankle plantarflexion average power 60°·s^{-1} (W)					(~) p>0.05	(~) p>0.05	(↑) Δ9.12±2.63 p=0.0132
	Ankle plantarflexion average power 180°·s^{-1} (W)					(~) p>0.05	(~) p>0.05	(↑) Δ12.47±3.53 p=0.0310
	Ankle plantarflexion average power 300°·s^{-1} (W)					(~) p>0.05	(~) p>0.05	(~) p>0.05
Symons et al., 2005		Concentric (mean±SD)	Eccentric (mean±SD)	Concentric (mean±SD)	Eccentric (mean±SD)	Concentric	Eccentric	
	Knee extensors peak isometric torque (90°)	130.6±54.0	142.0±39.8	151.8±61.2	176.0±44.7	(↑) p<0.01; Δ%: 17.3	(↑) p<0.01; Δ%: 25.5	
	Knee extensors peak concentric torque (90°·s^{-1})	93.6±40.4	107.5±30.7	113.9±48.3	116.3±26.1	(↑) p<0.01; Δ%: 22.1	(↑) p<0.01; Δ%: 10.0	
	Knee extensors peak eccentric torque (-90°·s^{-1})	161.9±62.6	168.5±40.0	191.4±76.8	207.1±35.6	(↑) p<0.01; Δ%: 17.9	(↑) p<0.01; Δ%: 26.0	
	Knee extensors concentric power (W)	75.5±37.2	83.5±32.8	104.4±41.0	98.1±28.7	(↑) p<0.01; Δ%: 51.8	(↑) p<0.01; Δ%: 23.3	
	Self-paced gait speed (80m) (m/s)	NI	NI	NI	NI	(~) p>0.05	(~) p>0.05	
	Self-paced step test (20 two-step cycles) (s)	NI	NI	NI	NI	(↓) p<0.03 ➔ ≈ -7%	(↓) p<0.03 ➔ ≈ -6%	

Note. SE: standard error; SD: standard deviation; ES: effect size; NI: not informed; ↑: increase; ↓: decrease; ~: not altered; pEMG: EMG seen at peak torque; HS: high-speed training group; LS: low-speed training group.

Table 4. Quality assessment

	Laroche et al., 2008	Malliou et al., 2003	Signorile et al., 2002	Symons et al., 2005
Random sequence generation	Low	Unclear	Low	Low
Allocation concealment	Unclear	Unclear	Unclear	Unclear
Blinding of participants and personnel	Low	Low	Low	Low
Blinding of outcome assessment	Unclear	Unclear	Unclear	High
Incomplete outcome data	Unclear	Low	Low	High
Selective reporting	Low	Low	Low	Low
Other sources of bias	Low	Unclear	Low	Unclear

ness, pennation angle and fascicle length) were not outcomes of interest in the selected trials.

Quality assessment

Table 4 presents the results of the methodological quality assessment by two reviewers. None of the included trials presented a low risk of bias in all assessed items. In addition, two trials (Laroche, et al., 2008; Signorile, et al., 2002) presented most of the assessed items with a low risk of bias and two trials (Malliou, et al., 2003; Symons, et al., 2005) present most of the items with a high risk or unclear.

Discussion and conclusions

In this systematic review, we analyzed controlled trials addressing the effects of concentric and eccentric resistance training, either isolated or in combination, on lower extremity neuromuscular and functional parameters in older adults. To ensure a proper control of the muscle action performed, as well as control of load intensity and contraction velocity, randomized trials with resistance training performed on an isokinetic dynamometer were revised. Our main findings revealed a small number of controlled trials that allowed us to discuss the effects of concentric and eccentric resistance training programs on the elderly's muscular and functional performances. Furthermore, quality assessment revealed a low risk of bias in two studies (Laroche, et al., 2008; Signorile, et al., 2002) and a high risk of bias in the other two (Malliou, et al., 2003; Symons, et al., 2005) studies, making it difficult to determine the training programs exact effects. Nevertheless, a positive training effect on knee muscles' performance, and a lack of consideration to functional performance, were common observations among the included trials.

When aiming to determine training adaptations, the use of isokinetic dynamometer is fundamental since it permits to identify different stimuli from concentric and eccentric muscle actions. One could argue that isokinetic training is hard to be applied in the general population due to the need for the specific instrumentation. We understand that among the advantages of this type of equipment are the safe control of the load (Kuruganti, et al., 2006) (which is important for older individuals), the constant angular velocity (Hislop & Perrine, 1967) (which controls the effect of velocity on force production, as demonstrated by the force-velocity curve). Additionally, it is possible to accommodate the maximal muscle potential along the entire joint range of motion (Malliou, et al., 2003), and to set the load separately to elicit similar effort for both the concentric and eccentric phases of the movements (which is important considering that eccentric action elicits greater strength (Reeves, et al., 2009). Therefore, the isokinetic dynamometer allows for controlling several of the intervening parameters on muscle force-production capacity, which can have a confounding effect on the training outcomes and mechanisms of neuromuscular adaptation.

The analyzed trials' results remain unclear whether functionality and strengthening outcomes in older people differ between training stimuli that involve concentric, eccentric, or concentric and eccentric actions combined into a training program. The concomitant assessment of muscular and functional performances from the training programs was not common in the trials, and many of the available studies in the searched literature were limited due to the lack of a control group or other comparative group, which led to their exclusion from the present review.

Concentric training was the most popular configuration of isokinetic training among the included trials. Isokinetic concentric (knee extensors and flexors) training compared with a control group was performed in three of the four included trials (Laroche, et al., 2008; Malliou, et al., 2003; Signorile, et al., 2002). All trials reported improvement in neuromuscular parameters, but none considered functional capacity assessment in the trained elderly. The training programs improved knee extensor isometric (Laroche, et al., 2008) and concentric torques (Malliou, et al., 2003), and reduced antagonistic coactivation (Laroche, et al., 2008). This reduced coactivation may benefit movement coordination (Kuruganti, et al., 2006), improving efficiency during activities of daily life (e.g. rising from a chair, climbing stairs). Although power is an important functionality component for the older adult, no modifications in the rate of torque development and neuromuscular activation were observed in response to training, despite of the adopted training velocities (Laroche, et al., 2008).

Signorile et al. (2002) developed a concentric training program at two different angular velocities (knee: $60\cdot s^{-1}$ and $270^{o}\cdot s^{-1}$; ankle: $60\cdot s^{-1}$ and $180^{o}\cdot s^{-1}$), and found that knee flexors power had no improvement at the assessed velocities ($60^{o}\cdot s^{-1}$, $180^{o}\cdot s^{-1}$ and $300^{o}\cdot s^{-1}$). Knee extensors power did not change for the lower-velocity training group. Conversely, a high-velocity training improved knee extensor power at the two greater angular velocities ($180^{o}\cdot s^{-1}$ and $300^{\circ}\cdot s^{-1}$). The use of high-velocity training can be a strategy for improving rapid reactions to perturbations (e.g., reaction during an imminent fall, a change of direction or to stop or initiating a movement when an unexpected event occurs), which is an ability that decreases with aging.

When the ankle muscles were trained, there were improvements in dorsiflexion torque at the different tested velocities, regardless of the training velocity (Signorile, et al., 2002). Results were different for ankle plantarflexors. While the high-training velocity did not improve performance, the low-training velocity improved power performance at lower angular velocities, showing evidence for the training velocity specificity. These results suggest that combining explosive movements for the lower extremity can selectively benefit different muscular groups.

Trainings focusing on ankle muscles are also important. The capacity to activate the dorsiflexor muscles and generate greater dorsiflexion during the swing phase of gait leads to a reduced risk of toe contact with obstacles (Begg & Sparrow, 2006), preventing trips and subsequent falls. Moreover, ankle plantarflexor strength is important during the propulsion phase of walking. However, most of the weight bearing exercises and weight-lifting machines rely on the participant's ability to perform full range of motion at the ankle throughout the exercise, which is different from the isokinetic dynamometer where the exercise performance can be determined throughout the joint's full range of motion.

Concentric and eccentric contractions can lead to different muscle structural adaptations (Franchi, Reeves, & Narici, 2017). Concentric contractions lead to greater improvements in the pennation angle, due to the parallel addition of sarcomeres (Reeves, et al., 2009). On the other hand, eccentric actions lead to greater improvements in fascicle length, due to the addition of in-series sarcomeres (Reeves, et al., 2009). However, the included studies did not investigate muscle structural parameters, and therefore there is still a lack of muscle structural parameters adaptations in the literature of controlled resistance training trials.

Only one study compared the effects of concentric versus eccentric training, performed on the isokinetic dynamometer, on muscular and functional parameters in older adults (Symons, et al., 2005). In this study, both training modalities improved knee extensors strength (isometric, concentric and eccentric strength), knee extensors concentric power (which was higher in the concentric than in the eccentric group), and performance in self-paced step test (Symons, et al., 2005). However, a training specificity seems to exist, because eccentric training increased 8% more eccentric torque than the concentric training, with the same occurring in the concentric torque, which was 12% greater in the concentric group compared to the eccentric training group. One practical application of this result is the identification of which muscle action type is more impaired in the older adult and choosing the equivalent resistance training for his/her specific needs. Furthermore, the results suggest that, if both muscle actions need attention, a combined training could be more adequate. However, the load control for concentric and eccentric actions in the same training session can be difficult to be determined due to the known different capacities of force production during concentric and eccentric contractions.

Gait speed did not change in response to different trainings, most likely because only knee extensors were trained. Hip extensors and ankle plantarflexors have significant correlation with preferred gait speed, but the knee extensors do not (Muehlbauer, Granacher, Borde, & Hortobagyi, 2018), which suggest that older adults strength training should also focus on hip and ankle muscles.

All trials reported neuromuscular parameters improvement, but only one considered the assessment of functional capacity (Symons, et al., 2005). None considered muscle structure. Structural parameters can elucidate the strength gain mechanisms, and therefore need to be investigated in controlled trials.

Another important aspect is the methodological quality of the included trials. Despite the fact that some parameters were well controlled, allocation concealment, for example, was unclear in all studies, and blinding of outcome assessment was also unclear or classified with a high risk of bias. These results, combined with the low number of trials about the topic of interest, show the urgent need for controlled trials with a high methodological quality.

From the trials included in this review, it is possible to observe that all training programs improved lower limb strength. However, the improvements are dependent on the training velocity, trained muscular groups, and muscle action. As the influence of these exercise configuration parameters are difficult to control in exercises performed with free weights or with weightlifting machines, understanding the mechanisms using controlled conditions is still necessary.

When structuring training programs for older individuals, the advantages of each of these parameters should be considered, aiming at improving several aspects that are impaired by aging. For example, training programs with different angular velocities improve the capacity to perform daily tasks requiring slow or rapid movements, contributing to the maintenance of older adults' physical independence. Additionally, if older people have impairment concerning a specific task, physicians should use the most helpful training modality for that impairment (with specific characteristics of velocity, load, muscular groups and contraction type). Moreover, if there is a global mobility difficulty, trainings that are more comprehensive might be more efficient (e.g., combining two velocities).

In conclusion, positive effects of concentric training compared to a control condition were consistent across the studied trials. Similar effects of concentric and eccentric training were found on neuromuscular parameters, but only one study addressed this issue. A common characteristic across the included trials is the lack of consideration of the effects from different training configurations on functional performance related to the elderly's independence. Due to the low number of studies, there is a need for new controlled trials, with high methodological quality, comparing the effects of concentric and eccentric training programs on neuromuscular (including muscle structure) and functional parameters in older adults.

When designing training programs for older adults, an isokinetic concentric training for knee extensors and flexors and ankle plantarflexors and dorsiflexors leads to improvements of neuromuscular factors (concentric strength, power, rate of torque development and muscle activation). Furthermore, a comparison between an isokinetic concentric and an eccentric strength training shows that they present similar results on neuromuscular parameters (isometric, concentric and eccentric torque and concentric power). Most of the included studies did not focus on functional parameters and none of them focused on muscle structural parameters. Therefore, the effects of these two isokinetic training modalities on the older adults' functional tasks and muscle structure remain unknown.

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Correspondence to:
Prof. Marco A. Vaz, Ph.D.
Exercise Research Laboratory
School of Physical Education, Physical Therapy and Dance
Federal University of Rio Grande do Sul
Felizardo Street, 750, Postal Code 90690-200, Porto Alegre, RS, Brazil
E-mail: marco.vaz@ufrgs.br