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MOBILIDADE FUNCIONAL EM IDOSOS: INFLUÊNCIA DE PARÂMETROS MUSCULARES E DE TREINAMENTO

Porto Alegre
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MOBILIDADE FUNCIONAL EM IDOSOS: INFLUÊNCIA DE PARÂMETROS MUSCULARES E DE TREINAMENTO

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RESUMO

A manutenção da qualidade de vida e da independência dos idosos está diretamente relacionada com a funcionalidade, a qual depende da estrutura e função do sistema musculoesquelético. Entender a relação entre parâmetros musculares e a funcionalidade em idosos possibilita delinear programas de treinamento adequados para prolongar a independência funcional dessa população. Nesse sentido, estudos mostram que o treinamento de força leva a ganhos de estrutura e função muscular, e de funcionalidade. Tarefas funcionais são realizadas utilizando diferentes tipos de contrações musculares. Porém, na literatura não há um consenso sobre a relação entre os parâmetros musculares e a funcionalidade em idosos, nem os efeitos de treinamentos de força utilizando diferentes tipos de contrações sobre a estrutura e função musculares, e a funcionalidade. Assim, o presente estudo teve como objetivos (1) identificar quais parâmetros estruturais e de função muscular de membros inferiores apresentam melhor relação e podem explicar o desempenho em tarefas funcionais; (2) revisar sistematicamente a literatura quanto aos efeitos de treinos com diferentes tipos de contrações para idosos; e (3) investigar os efeitos de um treinamento de força concêntrico versus um treinamento concêntrico-excêntrico para a musculatura flexora e extensora do joelho sobre parâmetros de estrutura e função muscular e funcionalidade de homens idosos. Para atingir esses objetivos, a presente tese foi dividida em quatro capítulos. No Capítulo 1, verificou-se a relação entre parâmetros de estrutura e função muscular de membros inferiores (arquitetura muscular, eco intensidade e força isométrica) e parâmetros funcionais (testes *Timed Up and Go* e sentar-e-levantar, marcha no solo e marcha com transposição de obstáculo em velocidade preferida e máxima). No Capítulo 2, investigou-se parâmetros estruturais e de função muscular de flexores e extensores de joelho (torque isométrico, concêntrico e excêntrico, potência, taxa de produção de força, eco intensidade e arquitetura muscular), considerando, assim, além dos parâmetros investigados no Capítulo 1, parâmetros de força dinâmica e os relacionando com diferentes testes funcionais (sentar-e-levantar, *Timed Up and Go*, equilíbrio, velocidade de marcha, caminhada de seis minutos, subida e descida de degraus e salto vertical). Os principais achados desses estudos demonstram que a estrutura dos músculos vasto lateral e tibial anterior, e o torque concêntrico de extensores de joelho foram os parâmetros com melhor relação com a funcionalidade. Para verificar a influência do treino de força com diferentes tipos de contração sobre parâmetros de estrutura e função muscular e funcionalidade, no Capítulo 3 realizou-se uma revisão sistemática de estudos envolvendo treinamento de força isocinética para membros inferiores em idosos. Verificamos que tanto o treino de força concêntrico quanto o excêntrico apresentam efeitos positivos sobre a função muscular e a funcionalidade. Porém, a capacidade funcional foi investigada em apenas um estudo, e a estrutura muscular em nenhum deles. Além disso, nenhum dos estudos realizou um treino combinando diferentes tipos de contração, o que poderia ser mais benéfico para os idosos. Portanto, no Capítulo 4 são apresentados dados preliminares do estudo envolvendo treinamento de força para homens idosos, onde um grupo realizou treinamento exclusivamente concêntrico e outro treino concêntrico-excêntrico para flexores e extensores de joelho. Os indivíduos foram avaliados quanto aos mesmos parâmetros do Capítulo 2 em três momentos: basal, duas semanas após a avaliação basal e ao final do treinamento. Os dados preliminares demonstram que ambos os grupos de treino apresentaram ganhos tanto musculares quanto funcionais após o treinamento.

Palavras-chaves: envelhecimento, treinamento de força, mobilidade.

ABSTRACT

Aging with quality of life is the biggest challenge for the elderly. Quality of life and independence maintenance are directly related to functionality, which depends on the musculoskeletal system structure and function. Understanding the relationship between muscular parameters and functionality in the elderly allows designing appropriate training programs to prolong this population's functional independence. In this sense, studies show that the strength training lead to muscle structure and function and functionality gains. Functional tasks are performed utilizing different types of muscle contraction. However, there is no a consensus in the literature considering the relationship between muscle parameters and functionality in the elderly, nor considering the effects of strength trainings utilizing different contraction types on muscle's structure and function, and on functionality. Thus, the present study had as objectives (1) to identify which lower limbs structural and muscular function parameters present better relation and can explain performance in functional tasks, (2) systematically review the literature about the effects of trainings with different contraction types for older subjects, and (3) to investigate the effects of concentric strength training versus concentric-eccentric training for knee flexors and extensors muscles on parameters of muscle structure and function and functionality in the elderly. To achieve these objectives, this thesis was divided into four chapters. In Chapter 1, the relationship between structural parameters and lower limb muscle function (muscular architecture, echo intensity and isometric strength) and functional parameters (Timed Up and Go and sit-to-stand tests, gait with and without obstacles at the preferred and maximum speed) was verified. In Chapter 2, the relationship between knee flexors and extensors structural parameters and muscle function (isometric, concentric and eccentric torque, power, rate of force production, echo intensity and muscular architecture) and functionality (sit-to-stand, Timed Up and Go, balance, walking speed, six-minute walk test, stair ascent and descent, and vertical jump) was investigated, considering, in addition to the parameters investigated in the Chapter 1, parameters of dynamic strength. The main findings demonstrate that the vastus lateralis and tibialis anterior muscles structure, and the knee extensor concentric torque were the parameters with better relation with functionality. In order to verify the influence of the strength training with different types of contractions on parameters of structure and muscular function and functionality, a systematic review of studies involving lower limb strength training in the elderly, performed on isokinetic dynamometers, was carried out in Chapter 3. We found that both concentric and eccentric strength training have positive effects on muscle function and functionality. However, functional capacity was investigated in only one study, while muscle structure in none of them. In addition, no studies performed a strength training combining different types of contraction, which could be more beneficial for older individuals. Therefore, Chapter 4 presents preliminary data from the study involving strength training for elderly men where one group performed exclusively concentric training and another concentric-eccentric training for knee flexors and extensors. Subjects were assessed for the same parameters of Chapter 2 at three different times: baseline, two weeks after baseline assessment and after training. Preliminary results indicate that both groups presented muscular and functional gains after the training period.

Keywords: aging, strength training, mobility.

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APRESENTAÇÃO

A expectativa de vida da população mundial vem aumentando ao longo dos últimos anos. Para que os indivíduos possam viver por mais tempo com boa qualidade de vida, mantendo-se funcionalmente independentes, se torna necessária a investigação dos efeitos do envelhecimento para a população idosa, principalmente de fatores que influenciam na realização de suas atividades de vida diária, bem como de estratégias que visem a manutenção da sua qualidade de vida, por meio de uma boa capacidade funcional.

Assim, a presente tese tem como objetivos: (1) identificar quais parâmetros estruturais e de função muscular de membros inferiores apresentam melhor relação e podem explicar o desempenho em tarefas funcionais; (2) revisar sistematicamente a literatura quanto aos efeitos de treinos de força com diferentes tipos de contrações musculares para idosos; e (3) determinar os efeitos de um treinamento de força concêntrico versus um treinamento concêntrico-excêntrico para a musculatura flexora e extensora do joelho sobre parâmetros de estrutura e função muscular e funcionalidade de homens idosos.

Para isso, essa tese está dividida em uma introdução geral e quatro capítulos. Todos os capítulos estão escritos na língua inglesa, sendo que os três primeiros foram escritos em forma de artigo e estão formatados de acordo com as normas do periódico onde cada um será submetido. Já o capítulo 4, trata-se de um estudo descrevendo dados de um ensaio clínico randomizado, o qual ainda está em andamento, e não está em formato de artigo.

Para determinar a relação entre parâmetros de estrutura e função muscular com a funcionalidade, no Capítulo 1, intitulado "*Determinants of functionality in older adults: the role of lower limb muscle architecture, echo intensity and isometric strength*", investigamos quais parâmetros musculares dos membros inferiores apresentaram correlação e conseguiram explicar a funcionalidade em idosos. Os parâmetros musculares investigados foram espessura muscular, ângulo de penação, comprimento de fascículo, eco intensidade e força isométrica. A capacidade funcional foi determinada por meio dos testes *Timed Up and Go*, sentar-e-levantar de cinco repetições e marcha no solo com e sem transposição de obstáculo, realizada em velocidade preferida e em velocidade máxima. Para as tarefas de marcha, a velocidade e as distâncias verticais entre pé e obstáculo foram os parâmetros de interesse.

Como no Capítulo 1 investigamos somente parâmetros de força isométrica, com um foco principal em tarefas de marcha, no Capítulo 2, intitulado "*Are knee extensor and flexor muscles' characteristics associated with functionality in older individuals*?", o objetivo foi de verificar se parâmetros musculares de extensores e flexores de joelho apresentam correlação com a capacidade funcional em idosos, incluindo, assim, a análise de diferentes parâmetros de força dinâmica, bem como outros testes funcionais, além dos investigados no capítulo anterior. As medidas de estrutura e função muscular foram espessura muscular, ângulo de penação, comprimento de fascículo, eco intensidade, torque isométrico, concêntrico e excêntrico, potência e taxa de produção de força. Já a capacidade funcional foi avaliada por meio dos testes *Timed Up and Go*, caminhada de seis minutos, sentar-e-levantar de trinta segundos, salto vertical, equilíbrio, velocidade de marcha e subida e descida de degraus.

Considerando estratégias de intervenção para a população idosa, para atingir o objetivo de investigar os efeitos de treinos de força utilizando diferentes tipos de contrações para indivíduos idosos sobre parâmetros musculares e funcionais, no Capítulo 3, intitulado "*Muscular and functional responses to concentric and eccentric training in older adults: a systematic review*" realizamos uma revisão sistemática, a qual objetivou investigar os efeitos do treino de força concêntrico ou excêntrico, realizado com somente um tipo de contração ou combinando ambas, sobre parâmetros musculares e funcionais de membros inferiores em idosos.

Como poucos estudos foram encontrados, investigando os efeitos do treino de força isocinético, com diferentes tipos de contração, e nenhum deles realizou um treino combinando os dois tipos de contração, realizamos um ensaio clínico randomizado. O mesmo é apresentado no Capítulo 4, intitulado "*Effects of concentric versus concentric-eccentric resistance training for older men: a randomized controlled trial*", onde relatamos resultados descritivos preliminares do ensaio clínico randomizado, o qual ainda está em andamento. O mesmo objetivou verificar os efeitos de um treino de força concêntrico e de um treino de força concêntrico-excêntrico para a musculatura flexora e extensora de joelho, realizado com idosos. Nele, investigamos os efeitos dos treinos sobre parâmetros musculares (espessura muscular, ângulo de penação, comprimento de fascículo, eco intensidade, torque isométrico, concêntrico e excêntrico, potência e taxa de produção de força) e funcionais (testes *Timed Up and*

Go, caminhada de seis minutos, sentar-e-levantar de trinta segundos, salto vertical, equilíbrio, velocidade de marcha e subida e descida de degraus) de idosos.

INTRODUÇÃO

Nos últimos anos, a expectativa de vida da população mundial vem aumentando. Dados da Organização Mundial da Saúde [1] mostram, por exemplo, que a expectativa de vida aos 60 anos, passou de 18,8 anos no ano de 2000 para 20,5 anos em 2016, mostrando que, quando o indivíduo atinge os 60 anos, espera-se que ele viva por mais tempo.

O processo de envelhecimento é acompanhado por diversas alterações na estrutura e função muscular dos indivíduos, bem como na funcionalidade. Considerando as alterações na estrutura e função muscular, o processo de envelhecimento leva a uma redução da força muscular e da massa muscular [2-7], alterações nas fibras musculares, como redução do tamanho e da quantidade de fibras [2, 6], e também alterações na arquitetura muscular, como redução do ângulo de penação e do comprimento de fascículo [8]. Associado a isso ocorre uma piora na funcionalidade [3], que está relacionada à capacidade de um indivíduo realizar suas tarefas de vida diária, bem como à sua independência funcional. Essas alterações também aumentam o risco de quedas nos idosos [3].

Devido ao fato que o número de idosos vem aumentando, que eles estão vivendo por mais tempo e que todas essas alterações ocorrem com o processo de envelhecimento, entender como as relações entre a estrutura e a função muscular e a funcionalidade ocorrem, torna-se importante para a estruturação de intervenções visando a manutenção da independência funcional dos idosos.

Alguns estudos apresentam as relações entre os parâmetros de estrutura e função muscular com a capacidade funcional, sendo algumas associações ainda controversas na literatura [9-14]. Além disso, de forma geral os estudos abordam poucos parâmetros em uma mesma análise como, por exemplo, focando em fatores relacionados a apenas uma articulação ou a apenas um tipo de força (ex.: isométrica). Adicionalmente, a associação entre os parâmetros de estrutura e função muscular com o desempenho na marcha ainda é pouco explorado na literatura.

Considerando que as tarefas de vida diária, como levantar de uma cadeira, sentar em uma cadeira, caminhar em diferentes condições e subir e descer degraus, envolvem diferentes músculos dos membros inferiores, envolvem a realização de diferentes tipos de contração (isométricas, concêntricas e excêntricas) e que esses movimentos necessitam ser realizados em diferentes velocidades, uma investigação mais abrangente desses fatores se torna necessária. Dentre eles, se encontram os parâmetros estruturais dos músculos (espessura muscular, ângulo de penação, comprimento de fascículo e eco intensidade) e os de função muscular (força isométrica, concêntrica e excêntrica, potência e taxa de produção de força).

Na busca de estratégias eficazes para melhora dos parâmetros de estrutura e função muscular e da capacidade funcional de indivíduos idosos, vem sendo demonstrado que o treino de força apresenta efeitos positivos [15-18]. Levando-se em conta que as tarefas de vida diária envolvem diferentes tipos de contração, talvez um treino de força envolvendo mais de um tipo de contração possa ter melhores efeitos. Treinos de força envolvendo contrações concêntricas ou excêntricas podem levar a diferentes adaptações musculares [19]. Assim, um aprofundamento na investigação acerca dos efeitos do treino de força envolvendo diferentes tipos de contração também se faz necessária, uma vez que poucos estudos investigam essa comparação.

Diante disso, duas questões principais norteiam o presente trabalho: (1) quais são os fatores de estrutura e função muscular que estão melhor associados com e podem explicar a funcionalidade de idosos?, e (2) quais são os efeitos de treinos de força envolvendo diferentes tipos de contrações musculares sobre a estrutura e função muscular e a funcionalidade de idosos?

CHAPTER 1 - DETERMINANTS OF FUNCTIONALITY IN OLDER ADULTS: THE ROLE OF LOWER LIMB MUSCLE ARCHITECTURE, ECHO INTENSITY AND ISOMETRIC STRENGTH

1.1 Abstract

Background: The aging process leads to several adaptations in the musculoskeletal system structure and function. Most of these adaptations are associated with a loss of mobility and independence. However, it is still unclear which lower limb muscular parameters, considering the musculature of the hip, knee and ankle joints, could better relate to and explain functional performance in the elderly, mainly during gait tasks. Therefore, our aim was to determine which lower limb muscular parameters correlate and explain the older individuals' functional performance.
Methods: Muscle structure was determined in 15 older individuals (75.4±5 years) through measures of architecture and echo intensity from lower limb muscles (vastus lateralis, biceps femoris, rectus femoris, tibialis anterior and gastrocnemius medialis). Muscle function was assessed through isometric strength of hip, knee and ankle muscles, and functionality was evaluated through the Timed Up and Go test, five-repetitions sit-to-stand test, overground gait and gait with obstacle crossing at preferred and maximal speeds.
Findings: Our main results show that isometric strength was, in general, not related with functional parameters, and that tibialis anterior and vastus lateralis structure (mainly muscle thickness and echo intensity) were the parameters most related to functional capacity in older individuals (significant correlations with the sit-to-stand test, step length, speed and lead and trail limb toe clearances).
Interpretation: Tibialis anterior and vastus lateralis muscles deserve attention when aiming to maintain independence through functional improvements in the elderly.

Keywords: Aging; Ultrasonography; Kinematics; Muscle strength; Walking.

1.2 Introduction

The world population is aging fast [1], and one of the main concerns is to maintain the older adults physically independent. This is a challenge in face of the many deleterious adaptations of different body systems in response to age increase, for example, adaptations in the muscle's structure and function [2-8].

In order to discuss functionality and independence in the elderly it is necessary to consider different conditions of locomotion and daily life tasks. Elderly are known to have difficulty in sit-to-stand performance, which has been used as a parameter to assess muscle function [20]. In addition, walking tasks, such as the Timed Up and Go test, are commonly used to identify elderly at risk of falling [21]. A great interest in the assessment of perturbed gait in the elderly, including obstacle crossings tasks [22], has also been observed. Locomotor ability is one of the main independence components in older individuals, and the musculoskeletal system plays an important role in mobility [23]. Loss of muscle mass and muscle strength is related to a loss of mobility and independence [24]. However, muscle strength results from a combination of different neuromuscular parameters, including muscle architecture [25, 26], muscle activation [25] and echo intensity [9].

Muscle structural parameters are related to the muscles' function [9, 25-27]. Muscle thickness, for example, is associated with the quantity of muscle mass, while pennation angle is related with the number of in parallel sarcomeres and fascicle length with the number of in series sarcomeres. In addition, the echo intensity represents the muscle quality, once that it considers the quantity of contractile material into the muscle [27]. With the aging process, it is known that these parameters are altered, occurring a reduction in the muscle thickness [2, 6], pennation angle and fascicle length [8] and a worsening in the muscle quality (echo intensity), with the elderly showing a greater quantity of non-contractile intramuscular material [27]. Additionally, isometric strength is largely used to verify the muscle general capacity to produce strength and the use of handheld dynamometers to evaluate it are also largely utilized in the clinical practice.

Previous studies showed that some muscles' structure and function are related to the elderly functional capacity [9, 10]. However, most of the studies considered only the knee muscles or only one joint, and it remains still not clear which of these factors are more important to maintain older adults physically independent, considering the musculature of the hip, knee and ankle joints. Knowing the relationship between these parameters and functionality in the elderly might help health professionals identifying those individuals at higher risk of losing independence, and designing intervention programs focused on the most important factors.

In this sense, in this study we aimed at verifying the relationship between lower limb muscular parameters and functionality in the elderly. To achieve this goal, we determined which muscular parameters were correlated and were able to explain the older individuals' functional capacity. Specifically, we investigated whether the lower limb muscles structure (thickness, pennation angle, fascicle length and echo intensity) and function (isometric strength) were able to explain the performance in functional tasks. These tasks included the five-repetitions sit-to-stand test (STS), Timed Up and Go test (TUG), overground gait (speed and step length) and gait kinematics with obstacle crossing (toe and heel clearances and speed) at different gait speeds.

1.3 Methods

1.3.1 Participants

Fifteen community-dwelling older individuals participated in our study (75.4±5 years old; body mass 68.6±14.8 kg; height 1.57±0.11 m; 9 women and 6 men; BMI 27.77±4.65 kg/m^2, body fat of 28.9±4.6%). All participants received detailed explanation about the aims of the study and the procedures. Before starting participation, they signed an informed consent form. The local institution ethics committee approved this study (IRB 2.034.508), and all procedures were conducted according to the Declaration of Helsinki. To be included, participants should be able to walk independently, do not have auditory, vestibular, visual and/or neuromusculoskeletal severe impairments, should not systematically practice exercises, and should not present severe cognitive impairments (Mini Mental State Examination [28] mean score was 28.2±1.3, above the 23 cutoff point [28]).

1.3.2 Study design

This is a cross-sectional study with the goal of evaluating older adults' functional and muscular parameters. Data collection was performed in two separate days, with at least 48h between them. On the first day, all participants answered the Mini Mental State Examination and underwent anthropometric measures (body mass, height, skinfolds, lower limb, thigh and leg lengths, and knee and ankle diameters). Physical tests were divided into two blocks (one for each day), that were randomized between the participants. Muscle architecture and muscle echo intensity of all muscles, TUG and hip and ankle isometric strength were evaluated in the first test day, while STS, knee muscles isometric strength and gait evaluations were performed in the second day.

1.3.3 Muscle architecture and muscle echo intensity

Muscle architecture (thickness, pennation angle and fascicle length) and echo intensity of the rectus femoris (RF), vastus lateralis (VL), biceps femoris (BF), tibialis anterior (TA) and gastrocnemius medialis (GM) were measured using a B-mode ultrasound equipment (MyLab30 Gold, Esaote Inc., USA), with a linear array probe (60 mm, 7.5 MHz), which was coated with water-soluble transmission gel to provide acoustic contact. These muscles were chosen due to the fact that they prime movers on hip, knee and ankle flexion and extension movements. The probe was positioned parallel to the muscle fascicles and transverse to them in the architecture and echo intensity measurements, respectively. Scans were taken following locations previously utilized [29]. Participants were instructed to lie down and relax. Three images were obtained by the same investigator from each muscle, and used for data analysis (architecture and echo intensity). Data were collected bilaterally, and the mean of the three images from each lower limb was utilized for subsequent analysis. Images were analyzed through the Image J software (National Institute of Health, USA).

Echo intensity (muscle quality) was determined by mean gray scale analysis, and expressed in arbitrary units ranging from 0 (black) to 255 (white). Region of interest was selected to include as much as possible muscle quantity, avoiding bone and surrounding fascia [9]. Muscle thickness was determined as the mean distance between the superficial and deep muscle aponeuroses measured at five sites along the image [30]. Pennation angle was determined for each image using a fascicle showing good resolution and size within the image area, and calculated as the angle between the deep aponeurosis of the muscle and the fascicle [30]. Fascicle length was determined as the length of the fascicular path between the superficial and deep aponeuroses [30]. When fascicle length was greater than the probe surface, it was determined through extrapolation using a trigonometric function [31].

1.3.4 Maximal isometric strength

Maximal isometric strength was assessed bilaterally using a handheld dynamometer (MicroFET2, Hoggan Health Industries, USA). Three trials lasting five seconds were performed for each muscular group and the mean of the peak value from each lower limb (normalized by the body mass) was utilized for subsequent analysis. A 90s rest interval was observed between each trial. Participants were verbally instructed and encouraged to do their maximal effort. Table 1 describes the muscular groups evaluated, positions adopted, dynamometer placement and belts' positions.

Hip and knee strength was evaluated with the participant positioned on a table with the handheld dynamometer firmly attached to a custom made device built in PVC, similar to a previous study [32]. The dynamometer was mounted in one side of the device, and the other extremity, which had a larger basis, was fixed by the examiner to the wall to reduce undesired movements. For assessment of ankle's muscular groups, a height-adjustable seat and a custom-made device built in wood, which allowed height adjustment according to the participant's leg length, were used. Evaluations were performed at prone position with arms resting along the table and at seated and supine postures with arms crossed and resting on the chest. The first limb for assessment and the order of the muscular groups of each joint were randomized for each participant.

Table 1: Testing settings details for the isometric strength assessment.

Muscle group	*Position*	*Dynamometer placement*	*Belts' position*
Hip Flex	Supine, knee and hip tested at 90º of flexion [33]	Frontal aspect of the thigh, 5 cm proximal to the patella proximal edge [33]	ASIS and distal third of the non-evaluated thigh
Hip Ext	Supine, non-evaluated limb rested with the knee flexed at 90º, evaluated limb with knee and hip flexed at 90º	Posterior aspect of thigh, 5 cm proximal to the popliteal line	ASIS and distal third of the non-evaluated thigh
Hip Add	Supine, hip tested at neutral position, opposite knee and hip flexed [33]	Medial aspect of the leg, 5 cm proximal to the medial malleolus [33]	ASIS and distal third of the evaluated thigh
Hip Abd	Supine, evaluated lower limb at neutral position [33] and the opposite limb at the same position	Lateral aspect of the leg, 5 cm proximal to the lateral malleolus [33]	ASIS and thighs' distal third
Hip Int Rot	Prone, hip of the evaluated limb at neutral position and knee flexed 90º, opposite limb at neutral position [33]	Lateral aspect of the leg, 5 cm proximal to the lateral malleolus [33]	PSIS and thighs' distal third
Hip Ext Rot	Prone, hip evaluated at neutral position and knee flexed at 90º, opposite limb at neutral position [33]	Medial aspect of the leg, 5 cm proximal to the medial malleolus [33]	PSIS and thighs' distal third

Knee Flex	Sitting, hips and knees flexed at 90º [34]	Posterior aspect of the leg, just proximal to the ankle [34]	Thighs' distal third
Knee Ext	Sitting, hips and knees flexed at 90º [34]	Anterior aspect of the leg, just proximal to the ankle [34]	Thighs' distal third
Ankle Dorsi	Sitting, hips and knees flexed at 90º and ankle at neutral position	Above the dorsal surface of the foot, close to the metatarsal phalangeal joints	None
Ankle Plant	Sitting, hips and knees flexed at 90º and ankle at neutral position	Anterior aspect of the thigh, 5 cm above the upper border of the patella	None

ASIS: anterior superior iliac spines; PSIS: posterior superior iliac spines; Flex: flexors; Ext: extensors; Add: adductors; Abd: abductors; Int Rot: internal rotators; Ext Rot: external rotators; Dorsi: dorsiflexors; Plant: plantar flexors.

1.3.5 Timed Up and Go (TUG)

Participants were asked to rise from a standardized chair (with backrest and without armrests; height of 42 cm) without using their arms, walk 3 m, turn around a cone, return and sit down again [35]. They were oriented to do the TUG test in a safe and comfortable speed. Two trials were performed with a 60s rest interval, and the best time was used for subsequent analysis.

1.3.6 Five-repetitions sit-to-stand (STS)

A height-adjustable bench (without backrest) was used for this test. It was adjusted to maintain the hips and knees flexed at 90º degrees and the ankles at neutral position. Participants initiated seated, barefoot, with the feet separated approximately in the shoulder's width and arms crossed over the chest. They were instructed to perform the sit-to-stand movements at maximal speed [20]. Two trials of five repetitions were performed with 60s rest interval between them. The best time was used for subsequent analysis.

1.3.7 Gait

Gait assessment was performed in four situations: overground walking (1) at preferred speed and (2) at maximal speed, and overground gait with obstacle crossing (3) at preferred and (4) maximal speeds. Kinematic data were recorded using 15 infrared cameras (Bonita B10, Vicon Motion Systems, UK) sampling data at 120 Hz. Kinematic data were filtered with a fourth order Butterworth filter, with a cut-off frequency of 10 Hz. Spherical reflective markers of 14 mm diameter were attached to the participant's body according to the Plug-in Gait Lower Body Modeling, with extra markers placed in the frontal (over the hallux) and back (over calcaneus protuberance) of the shoe, and at each superior edge of the obstacle.

Three trials at each speed were registered for the overground gait and ten trials (five with each lower limb as the leading limb) at each speed for the obstacle crossing condition. At preferred speed, participants were requested to walk as normally as they do in daily life, and at the maximal speed condition they were instructed to walk "as fast as you can, safely, not running". For the obstacle trials, participants were not instructed about the first limb to cross the obstacle. Trials at preferred speed were always registered first. The condition (overground and obstacle) was randomized.

Participants walked with flat casual shoes, along an 8-m walkway. In the obstacle condition, the obstacle was positioned halfway in the walkway. It was made of polystyrene (length x width: 80 cm x 20 cm), with height corresponding to 30% of each participant's lower limb length (defined as the distance from the greater trochanter of the femur to the ground). For the overground condition, gait speed and step length (normalized to the participant's leg length) at each speed (preferred and maximal) were the parameters of interest. In the obstacle condition, for the preferred and maximal speeds, lead and trail limb (LL and TL) toe clearance (measured when the hallux was directly above the first obstacle markers), lead limb (LL) heel clearance (measured when the heel was directly above the last obstacle markers) and gait speed were determined.

1.3.8 Statistical analysis

Data normality was checked through the Shapiro-Wilk test. Pearson and Spearman's correlations were performed to verify the correlation between the variables of interest. Correlations were classified [direct (+) or inverse (-) correlation] as weak (0.1-0.35), moderate (0.36-0.67) or strong (0.68-1) [36]. When significant correlations were found, single regression or stepwise multiple regression analyses were performed for each variable. All tests were performed using SPSS 17.0 (IBM Corp., Armonk, USA), considering a significance level of 0.05.

1.4 Results

1.4.1 TUG and STS

TUG performance did not correlate with muscular parameters of older adults (Table 2). On the other hand, STS showed strong direct correlation with VL echo intensity (a greater time to perform five repetitions were associated with greater echo intensity, that represents a worse muscle quality), and moderate inverse correlation with the RF and VL thickness and isometric hip internal rotation strength (Table 2), indicating that those subjects with greater muscle thickness and strength did the test faster. In the model built with a multiple regression analysis, only VL echo intensity was a significant predictor of STS performance, explaining 46% of the variance in STS performance (Table 4).

1.4.2 Overground gait

A greater preferred speed was associated with a greater VL muscle thickness, hip external rotation strength, and ankle dorsiflexion strength (Table 2). The regression analysis included in the model only the VL thickness as a significant predictor, explaining 36% of the variance in speed (Table 4).

Maximal gait speed presented direct correlations with VL muscle thickness and TA pennation angle, while an inverse correlation was found for TA fascicle length (Table 2). VL muscle thickness (R^2=0.32) and TA fascicle length (R^2=0.30) were included in the regression model, explaining together 63% of the variance in maximal speed (Table 4). Problems related to multicollinearity were not found for these variables, observed through the low correlation between them, low values of variance inflation factors, and big tolerance.

At preferred gait speed, a reduced step length was associated with worse VL muscle quality (Table 2), which was also included in the regression model (R^2=0.27; Table 3). At maximal speed, step length presented significant inverse correlation with VL echo intensity, and positive correlation with RF and VL thickness, which indicates that the greater the step length the greater the RF and VL thickness and the better the VL quality. The regression analysis showed that only the VL echo intensity was a good predictor of the step length at maximal velocity (R^2=0.29; Table 4).

1.4.3 Obstacle gait

Maximal gait speed in the obstacle crossing trials showed inverse correlation with VL echo intensity (Table 2), that explained 26% of the variance in the gait speed (Table 3). Preferred speed did not correlate with the muscular parameters. At preferred gait speed, toe clearance of leading leg (the first leg crossing the obstacle) showed direct correlation with TA muscle thickness and knee flexor muscle strength. At maximal speed, direct correlations with toe clearance were found for the RF echo intensity and hip adduction strength, and again for TA thickness and knee flexion strength (Table 2). At preferred speed, only the TA thickness entered in the model (R^2=0.30; Table 4) and at maximal speed TA thickness (R^2=0.39) and RF echo intensity (R^2=0.35) were good predictors of the dependent variable, explaining 74% of the variance (Table 4). Multicollinearity problems did not occur for these variables, as low correlation between them occurred and low values of variance inflation factors and big tolerance were observed.

Only one significant correlation was found for trail limb (the second leg crossing the obstacle) toe clearance: an inverse correlation between toe clearance and VL pennation angle at preferred speed. It was included in the regression model, explaining 32% of the trail limb toe clearance (Table 3).

Considering the heel clearance, at preferred gait speed, heel clearance showed direct correlation with GM echo intensity and, at maximal speed, there was a direct correlation between heel clearance and RF echo intensity (Table 2). As shown in Table 3, both variables were included in the model, explaining, respectively 30% and 50% of the variance.

Table 2: Correlation coefficients between muscular and functional parameters. Significant correlations are highlighted.

	TUG	STS	Overground gait				Obstacle gait							
			Preferred Speed		Maximal Speed		Preferred Speed				Maximal Speed			
			Speed	SL	Speed	SL	Speed	LL TC	TL TC	LL HC	Speed	LL TC	TL TC	LL HC
Echo intensity														
Rectus femoris	-0.06	0.16	0.07	-0.004	0.07	-0.05	-0.03	0.47	0.29	0.46	-0.005	0.62*	0.28	0.70**
Vastus lateralis	0.40	0.71**	-0.40	-0.52*	-0.41	-0.54*	-0.46	0.21	0.49	0.50	-0.51*	0.10	0.50	0.40
Biceps femoris	-0.13	-0.29	0.17	-0.06	0.15	-0.07	0.02	0.34	0.07	0.27	0.08	0.36	0.07	0.48
Tibialis anterior	0.26	0.13	-0.40	-0.31	-0.44	-0.36	-0.31	0.11	0.13	0.47	-0.35	-0.03	0.11	0.32
Gastrocnemius Med	0.07	-0.04	-0.08	-0.02	-0.13	-0.07	-0.11	0.46	-0.02	0.55*	-0.07	0.45	0.01	0.35
Thickness														
Rectus femoris	-0.39	-0.57*	0.42	0.48	0.36	0.51*	0.34	0.07	-0.38	-0.25	0.23	0.08	-0.23	-0.21
Vastus lateralis	-0.50	-0.57*	0.60*	0.48	0.56*	0.53*	0.51	0.17	-0.26	-0.26	0.45	0.20	-0.18	-0.20
Biceps femoris	-0.28	-0.15	0.23	0.08	0.28	0.18	0.32	-0.17	-0.22	-0.25	0.33	-0.12	-0.18	-0.23
Tibialis anterior	-0.17	-0.26	0.35	0.21	0.34	0.16	0.15	0.55*	0.26	0.17	0.23	0.56*	0.29	0.13
Gastrocnemius Med	-0.17	-0.41	0.27	0.17	0.36	0.15	0.28	0.005	-0.04	-0.27	0.40	0.02	-0.09	-0.21
Pennation angle														
Rectus femoris	0.05	-0.36	0.03	0.003	0.12	0.18	0.08	-0.30	-0.48	-0.17	0.15	-0.36	-0.45	-0.39
Vastus lateralis	-0.19	-0.27	0.08	0.14	0.13	0.25	0.16	-0.18	-0.56*	-0.14	0.20	-0.27	-0.45	-0.34
Tibialis anterior	-0.35	-0.28	0.45	0.33	0.52*	0.31	0.32	0.22	0.34	-0.09	0.45	0.35	0.34	0.05
Gastrocnemius Med	-0.28	-0.34	0.30	0.34	0.41	0.44	0.35	-0.27	-0.29	-0.44	0.35	-0.28	-0.32	-0.44
Fascicle length														
Rectus femoris	-0.10	0.15	0.002	0.16	-0.16	-0.004	-0.02	0.15	0.09	-0.02	-0.22	0.14	0.19	0.06
Vastus lateralis	-0.12	-0.15	0.23	0.13	0.08	-0.005	0.14	0.31	0.43	-0.04	-0.02	0.40	0.43	0.21
Tibialis anterior	0.48	-0.05	-0.48	-0.31	-0.54*	-0.36	-0.41	-0.06	-0.41	0.13	-0.33	-0.11	-0.37	-0.02
Gastrocnemius Med	0.32	-0.06	-0.31	-0.25	-0.20	-0.27	-0.20	0.11	-0.15	0.20	0.06	0.25	-0.19	0.27
Isometric strength														
Hip Flexion	-0.19	-0.19	0.06	0.19	0.02	0.15	0.25	0.05	-0.31	0.02	0.19	0.10	-0.30	0.06
Hip Extension	0.13	0.39	-0.07	-0.24	-0.15	-0.28	-0.23	0.35	0.13	0.43	-0.25	0.28	0.24	0.14
Hip Abduction	-0.03	0.07	-0.07	0.09	-0.03	0.15	0.12	0.12	-0.21	0.11	0.06	0.10	-0.23	0.10
Hip Adduction	-0.34	-0.11	0.31	0.33	0.13	0.20	0.16	0.46	-0.03	0.21	0.01	0.55*	0.12	0.33
Hip Internal Rotation	-0.41	-0.58*	0.44	0.29	0.24	0.20	0.36	0.20	-0.12	-0.10	0.09	0.10	0.03	-0.09
Hip External Rotation	-0.49	-0.14	0.54*	0.42	0.44	0.42	0.40	0.26	-0.16	-0.05	0.23	0.25	0.01	-0.13
Knee Extension	-0.09	-0.04	-0.04	-0.03	-0.03	-0.01	-0.06	0.31	-0.11	0.43	0.001	0.18	-0.11	0.15
Knee Flexion	-0.44	-0.13	0.41	0.26	0.33	0.22	0.20	0.52*	0.12	0.25	0.16	0.54*	0.21	0.28
Ankle Dorsiflexion	-0.43	-0.16	0.58*	0.37	0.48	0.37	0.41	0.48	0.20	0.08	0.23	0.41	0.25	0.01
Ankle Plantar Flexion	-0.15	0.04	0.05	-0.001	0.02	-0.01	0.11	0.20	-0.05	0.17	0.05	0.13	0.03	-0.002

TUG: Timed Up and Go; STS: five-repetitions sit-to-stand; SL: step length; LL TC: lead limb toe clearance; TL TC: trail limb toe clearance; LL HC: lead limb heel clearance; Med: medialis. *(P<0.05); **(P<0.01).

Table 3: Simple linear regression equations.

Independent variable	Regression equation	R	R^2	P
Preferred Speed				
Step length	{[(-0.300) * VLEI] + 98.156}	0.52	0.27	0.047
Trail limb toe clearance	{[(-1.706) * VLPA] + 40.705}	0.56	0.32	0.028
Lead limb heel clearance	{[(0.144) * GMEI] + 0.375}	0.55	0.30	0.032
Maximal Speed				
Lead limb heel clearance	[(0.155 * RFEI] + 1.164]	0.70	0.50	0.003
Speed (obstacle gait)	{[(-0.005) * VLEI] + 1.444}	0.51	0.26	0.048

VLEI: vastus lateralis echo intensity; VLPA: vastus lateralis pennation angle; GMEI: gastrocnemius medialis echo intensity; RFEI: rectus femoris echo intensity.

Table 4: Multiple linear regression equations.

Independent variable	Regression equation	R	R^2	P
STS	[(1.046*VLEI) – 0.824]	0.68	0.46	0.007
Preferred Speed				
Speed (overground)	[(0.571*VLMT)+0.125]	0.60	0.36	0.016
Lead limb toe clearance	[(7.239*TAMT)+0.278]	0.55	0.30	0.033
Maximal Speed				
Speed (overground)	{[(0.683*VLMT)+(-0.046*TAFL)] + 1.045}	0.79	0.63	0.003
Step length	{[(-0.354)*VLEI] + 109.833}	0.54	0.29	0.037
Lead limb toe clearance	{[(7.863*TAMT)+(0.166*RFEI)] - 14.748}	0.86	0.74	<0.001

STS: sit-to-stand; VLMT: vastus lateralis muscle thickness; TAMT: tibialis anterior muscle thickness; TAFL: tibialis anterior fascicle length; VLEI: vastus lateralis echo intensity; RFEI: rectus femoris echo intensity

1.5 Discussion

Here we aimed to determine whether muscular lower limb parameters of the hip, knee and ankle correlate and to what extent they could explain functional capacity in older adults. Our main results indicate that, among the different muscular characteristics of the lower limbs muscles' structure and function, TA and VL muscle structure are the most related to functional performance in the elderly. A main application of our study is that knee extension and ankle dorsiflexion muscles should receive attention in training or rehabilitation programs aiming at functionality improvement in older adults. Furthermore, an ultrasound image assessment of VL and TA muscles before and after a training program period might help to determine the training impact on functionality.

Muscle thickness and echo intensity measures were those explaining more the elderly functionality. Isometric strength, a common measure in the elderly clinical assessment, and highly related to important parameters related to quality of life in the elderly [37], in general, was weakly related with functional capacity. Considering the tasks performed by the elderly, the generation of concentric and eccentric forces may be more related with the tasks' performance, and future studies should test the hypothesis of a stronger relationship between concentric and eccentric forces and functional capacity.

Kinematic of obstacle crossing is considered important to assess risk of falls. This is one of the first studies to investigate whether lower limbs' muscular parameters are related with toe and heel clearances. Regardless of gait speed, TA muscle thickness and isometric knee flexion strength showed direct relation with LL toe clearance, but only TA thickness was a good predictor. TA plays an important role in ankle dorsiflexion [38], which minimizes the risk for obstacle contact. Ankle dorsiflexors isometric strength was demonstrated to be the unique lower limbs strength parameter that predicted the older subjects fall status [39]. Considering that this musculature has an important role on the assessment of risk of trips, and that the use of handheld dynamometers for isometric strength assessment is an inexpensive procedure and easy to perform [33], we suggest that dorsiflexor isometric strength should also be included in elderly assessment routines.

In this regard, a previous study showed that LL toe clearance during gait initiation was not related with lower limbs' dynamic strength for older women [40]. The authors observed that the elderly utilized a strategy that moved the toe backward, away from the obstacle, crossing it with greater vertical distance, compared to young, that moved the toe straight up [40]. This pattern could be related to a TA weakness, leading to another movement pattern during obstacle crossing. However, it was not the case here, as there was no relation between dynamic strength and vertical clearance [40]. On the other hand, overground minimum foot clearance was associated with hip flexion, knee extension, knee flexion and ankle dorsiflexion muscles' isometric force, for at least one of the lower limbs in a previous study [41].

When obstacle crossing was performed at maximal speed hip adduction strength (in addition to knee flexion strength) also presented significant correlation with LL toe clearance. Such relation could be related to the strategy utilized for positioning the feet before obstacle crossing, which is associated with the vertical distance achieved and that alters the angular pattern of joint motion during crossing [42]. The association between the vertical clearances and RF and

GM echo intensities needs further investigation, as they were not expected. Regarding TL kinematics during obstacle crossing, the only muscular parameter showing a relationship was VL pennation angle, predicting 32% of its variance.

The investigations concerning the relationship between muscular parameters and gait speed during overground gait are more common in the literature. However, some parameters are still controversial. Here, preferred gait speed was correlated with VL muscle thickness, hip external rotation strength and ankle dorsiflexion strength. On the other hand, maximal gait speed correlated with VL thickness and TA pennation angle and fascicle length. It seems that when older adults need to walk at maximum speed, different parameters are important, but it is possible to note that the VL and TA structure and function need attention to improve gait speed. When the older need to walk at maximal speed, gait speed seems to be not only dependent from kinematic parameters, but also from muscular parameters.

At overground maximal speed, VL and GM pennation angle and fascicle length were not associated with gait speed, which supports previous suggestion from the literature [26]. Muscle quality did not correlate with the overground gait speed. A previous study showed that quadriceps echo intensity was not related to the preferred speed; however, RF echo intensity was [9]. Here, VL muscle thickness correlated with both preferred and maximal speed for overground gait. Previous studies showed no relation between quadriceps thickness and preferred speed [9], and significant relation for maximum speed [26]. A reduction in the maximum speed in older women accompanied during one year correlated only with a reduction in the VL thickness [43]. From our results and previous studies, VL thickness seems to be an important parameter related to gait speed. We found no association of gait speed and isometric strength. However, this relation is still controversial in the literature [9-12].

Our results showed that step length was significantly correlated with the VL muscle quality at both speeds, and with the RF and VL thickness at maximal speed. To the best of our knowledge, this is one of the first studies investigating the relation between step length and muscle structure for older adults. Isometric strength was not related with step length. However, previous studies showed some relation with knee extensors strength [11, 12].

TUG has a limited capacity to discriminate older individuals at high risk of falls [21]. Here, it was not associated with the muscular parameters. TUG is generally performed at preferred speed and, because of this, is not a challenging task for independent aging individuals, as our participants. This could explain the fact that VL and GM pennation angle and VL fascicle length were also not correlated with the TUG test in another study [26]. However, they found some relations with muscle thickness (VL, RF/VI and GM) and GM fascicle length [26].

STS correlated with VL muscle quality and thickness, RF thickness and hip internal rotation strength, with only the VL echo intensity being a significant predictor. The knee extensors echo intensity correlated with the STS for older subjects [9, 44], as well as the quadriceps thickness [44].

Considering the movements involved in STS performance, knee extensors strength and power are important when executing this task. However, despite the significant correlation with knee extensors muscle thickness, there was only a significant correlation with hip internal rotation strength, which could be related to a weakness of the primary movers, leading to compensations to perform the movement. This hypothesis needs to be confirmed in future studies. Knee extensors [10, 45, 46], ankle dorsiflexors [10, 46] and plantar flexors [10, 46] isometric strength were associated with the STS performance in some studies but, as in the present study, knee extensors were not correlated in another study [9].

1.6 Conclusions

This is one of the first studies investigating which muscular parameters (structure and function) relate with the vertical clearances during obstacle crossing. From our results, it seems that TA and VL structure (mainly echo intensity and thickness) play an important role on the elders' functionality an in reducing the risk of trips during gait, and should receive more attention when aiming to maintain the elders' independence. We suggest that future studies investigate the relation between functional capacity and concentric and eccentric strength and parameters that involve rapid movements (e.g. power and rate of force production). In this sense, in the Chapter 2, we will present a more deep investigation, considering those parameters of dynamic strength.

CHAPTER 2 – ARE KNEE EXTENSOR AND FLEXOR MUSCLES' CHARACTERISTICS ASSOCIATED WITH FUNCTIONALITY IN OLDER INDIVIDUALS?

2.1 Abstract

Functional capacity deteriorates due to different age-related adaptations. Identifying muscular aspects related with functional performance can be useful when designing exercise interventions for the elderly. Here we considered data from 13 older untrained men to verify correlations between knee extensors and flexors muscular parameters and functional capacity. Muscle architecture and echo intensity of rectus femoris, vastus lateralis and biceps femoris were assessed. In addition, isometric, concentric and eccentric torques, concentric power and rate of torque development were determined. Functional capacity was evaluated through eight different tests: Six-Minute Walk Test, 30-seconds sit-to-stand, countermovement jump, Timed Up and Go, balance, preferred gait speed, stair ascent and stair descent. Our main results indicate that knee extensors structure (mainly fascicle length) and concentric torque, at larger extent than isometric and eccentric torque, are related with functional capacity. Power was also correlated with performance in sit to stand and jump tasks. From these results, we may suggest that a strength-training program, combining concentric and eccentric contractions, mainly for the knee extensors, seems to be a good strategy to improve functionality of older individuals.

Keywords: Aging; Torque; Ultrasonography; Muscles; Knee.

2.2 Introduction

Throughout the normal aging process, functional capacity gradually deteriorates. Both the decrease in the level of physical activity, commonly observed in older adults [47], and alterations in the muscle's structure and function [2, 3] are major factors leading to loss of physical independence.

Daily life activities require a variety of movements performed at different contractile conditions. Activities like rising up from a chair, sitting down, walking at different speeds, climbing stairs and jumping are examples of tasks involved in daily life. These tasks require recruitment of different muscles under different actions (i.e. isometric, concentric or eccentric), movement speeds, contraction velocities, and ranges of motion. Furthermore, some of them require a fast and high force production, which supports the importance of power production [48] and rate of torque development for functionality of older individuals [9].

Specific physical exercise configurations can result in specific muscle adaptations in the elderly, such as power improvement in response to explosive strength training [49]. However, when it comes to gains in functionality, a systematic review of the literature found that enrollment in physical exercise programs was more important to the challenged gait performance (i.e. gait with obstacles) than the type of exercise performed [50]. The authors suggest that muscle adaptations from different exercise configurations may account for the positive outcomes regarding functionality. The knowledge about which of these muscular parameters are related with physical independence, represented by functional tasks performance, is important to design successful physical training strategies. However, it is still not clearly stablished in the literature which parameters of muscle function and structure are correlated with different functional tasks in older individuals, as the results from different studies are not a consensus. Specifically, studies investigating this relation considering isometric, concentric and eccentric contractions are scarce, as well as those analyzing the relation between functionality and muscle architecture parameters.

In this study our aim was to determine whether knee extensor and flexor muscular parameters correlate with functional capacity in older men. We investigated if the structure (thickness, pennation angle, fascicle length and echo intensity) and the function (isometric, concentric and eccentric torque, concentric power and rate of torque development) of knee extensor and flexor muscles are correlated with performance in the following functionality tests: Timed Up and Go, Six-Minute Walk Test, 30-seconds sit-to-stand, countermovement jump height, balance, gait speed, and stair ascent and descent.

2.3 Methods

2.3.1 Participants

Thirteen community-dwelling older men (65 years or older; 73±5 years of age; body mass of 83.5±11.2 kg; height of 1.70±0 m; body fat percentage of 26.6±4.9) participated in the study. All participants received detailed explanation about the aims of the study and the procedures, and signed an informed consent form before starting the tests. The local institution ethics committee approved this research, according to the Declaration of Helsinki (IRB 2.034.508). Inclusion criteria were not having auditory, vestibular, visual and/or neuromusculoskeletal severe impairments, not reporting pain in the lower limbs, not being systematically enrolled in physical exercise, and not presenting severe cognitive impairments (mean score in the Mini Mental State Examination - MMSE was 27.8±1.8).

2.3.2 Study design

This study is part of a longitudinal ongoing study (NCT03206580) with the purpose of determining the effects of different types of strength training on muscular parameters and functionality of older adults. At the beginning of the study, elderly performed a basal assessment of functional performance, isometric, concentric and eccentric strength, and muscular parameters. Here, data from the participants' basal assessment are considered.

To complete the basal assessment, participants visited the laboratory in three separate days (with at least 72 h of interval between sessions). On the first day, they answered the MMSE, performed the anthropometric measures (body mass, height and skinfolds), the echo intensity and muscle architecture (i.e. structural muscular parameters) assessments, and performed two or three of the eight functional tests (i.e. functional assessment battery). Additionally, a familiarization with the isometric, concentric and eccentric contractions was performed on the isokinetic dynamometer. On the second day, they performed two or three of the functional tests and the isometric and concentric torque evaluations or the eccentric torque tests (i.e. torque assessment). Finally, on the third day, the remaining functional and torque tests were performed.

Functional tests were divided in three blocks (one block for each day) randomized for each participant. The type of strength tests was also randomized (concentric and isometric; or eccentric only), as well as the muscular group and the lower limb assessed first in each day. All randomizations were done using a sequence generated by the website Randomization.com.

2.3.3 Functional capacity

The battery of functional tests included in the study evaluated different aspects of functionality in the daily life context, and were selected due to their easy application in different settings including the clinical. A 1-min rest interval between the trials was considered for each test.

Balance – The unipodal static balance was evaluated bilaterally (two trials for each lower limb). Participants were asked to maintain the position (hip at anatomical position with one knee flexed) during 30 s, a time window used for fall risk screening [51]. The time the task was sustained (initial position, without touching the foot of the lower limb with the knee flexed on the ground) was registered up to 30 s. Two digital cameras (placed at sagittal and frontal planes) registered the task for subsequent analysis of the time the participant maintained the balance.

Timed Up and Go (TUG) - Participants were asked to rise from a standardized chair (with backrest and without armrests; height of 44 cm) without using the arms, to walk 3 m, turn around a cone, return and sit down again [35]. Participants were oriented to do the task at comfortable speed. Two trials were performed and the best time (registered with a stopwatch) was used for subsequent analysis.

Six-Minute Walk Test (6MWT) – Participants were instructed to walk at their maximal pace along a 30 m long flat walkway (delimited with cones) during six minutes. Time was registered for one trial, and the distance, in meters, measured.

Gait speed – Participants walked at preferred pace along a flat walkway 10 m long, delimited with two cones. They started 1 m before the walkway and stopped 1 m after. Two trials were performed and the best was considered for subsequent analysis. Time was registered with a stopwatch and the average speed was determined.

Stair ascent – The time, registered with a stopwatch, to step up 10 stairs as fast as possible was registered. The best value of two trials was used for analysis.

Stair descent – The time, registered with a stopwatch, to step down 10 stairs as fast as possible was registered. The best value of two trials was utilized for analysis.

30-seconds sit-to-stand (30STS) – A standardized chair (44 cm height) with backrest and without armrests, placed against a wall, was utilized [20]. Participants were instructed to do the test at maximal speed, aiming to perform the maximal number of complete repetitions during 30 s (registered with a stopwatch), with their arms crossed in front of the chest. Two trials were performed, and the maximal number of repetitions was used for analysis.

Countermovement jump – Participants initiated at standing position, feet at shoulder's width and hands at the waist. Kinematic data was collected at 30 Hz using a digital camera (Sony 16.1 MP), positioned at the sagittal plane. The movement of a marker positioned at the participant's greater trochanter was used to determine the jump height. The evaluator demonstrated the movement and a familiarization trial was done by each subject. Three trials were performed, and the best value was used for analysis. Data were analyzed through the software Kinovea (version 0.8.15).

2.3.4 Muscle architecture and muscle echo intensity

Thickness, pennation angle, fascicle length and echo intensity of the rectus femoris (RF), vastus lateralis (VL) and biceps femoris (BF) muscles were measured at rest using a B-mode ultrasound equipment (SSD 4000; Aloka Inc., Tokyo, Japan), with a linear array probe (60 mm, 7.5 MHz). The probe was coated with water-soluble transmission gel to improve acoustic contact. The probe was positioned parallel to the muscle fascicles and transverse to them in the architecture and echo intensity images, respectively. Scans were taken following locations described elsewhere [29]. Participants were instructed to lie down and relax. Three images for each analysis (architecture and echo intensity) were obtained from each muscle, always by the same researcher. Data were collected bilaterally, and the mean of three images from each lower limb was utilized for subsequent analysis. Images were analyzed in the Image J software (National Institute of Health, USA).

Echo intensity was determined by mean gray scale analysis and expressed in arbitrary units between 0 (black) and 255 (white). Region of interest was selected including as much as possible muscle area, avoiding bone and surrounding fascia [9]. Muscle thickness was determined as the mean distance between the superficial and deep muscle aponeuroses, which were measured at five sites along the image [30]. Pennation angle was determined for each image using the best fascicle, and calculated as the angle between the muscle deep aponeurosis and the fascicle [30]. Fascicle length was determined as the length of the fascicular path between the superficial and deep aponeuroses [30]. When greater than the probe surface, fascicle length was calculated through extrapolation and trigonometric function [31].

2.3.5 Peak torque (PT)

Knee flexors and extensors maximal isometric, concentric and eccentric torques were assessed bilaterally using an isokinetic dynamometer (Biodex System 3 Pro, Biodex Medical System, USA). Participants were positioned and firmly strapped on the dynamometer according to the manufacturer's recommendations for knee flexion and extension evaluations. They were verbally encouraged to perform their maximal effort at maximal speed along the total range of motion during the tests. Before the evaluations, participants completed a warm-up consisting of two series of ten submaximal concentric repetitions each at 90º.s^{-1}. A 2-min interval was observed between contraction sets. The peak torque was considered for subsequent analysis.

Isometric contractions lasted 5 seconds each and three trials were performed at two different positions for each muscular group: knee flexors at 30º and 90º, and knee extensors at 60º and 90º of knee flexion, respectively (0º=full extension). Knee flexion-extension concentric contractions were performed at 60º.s^{-1} and 180º.s^{-1}. Eccentric contractions were performed separately for each muscular group at 60º.s^{-1} and 120º.s^{-1}. Two series of 3 repetitions were performed at each speed, with a range of motion of 70º (90º-20º).

2.3.6 Power

Concentric power was determined during the maximal concentric tests at 60º.s^{-1} and 180º.s^{-1} for knee flexion and knee extension.

2.3.7 Rate of torque development (RTD)

RTD was determined during the maximal isometric voluntary contractions, for the peak torque trials. It was calculated for the first 50 ms and 200 ms (representing the early and late phases of torque production) after the onset of the isometric contraction (when the torque was equal or greater than 5% of peak torque), using the equation Δtorque.Δtime^{-1}. The participants were instructed to perform their maximal effort at maximal speed.

2.3.8 Statistical analysis

Data normality was tested through the Shapiro-Wilk test. Pearson's and Spearman's correlation tests were performed. Correlations were classified [direct (+) and inverse (-)] as weak (0.1-0.35), moderate (0.36-0.67) or strong (0.68-1) [36]. All tests were performed using SPSS 17.0 (IBM Corp., Armonk, USA), considering a significance level of 0.05.

2.4 Results

2.4.1 Balance

Balance was not related with structural, torque, power nor RTD parameters (Table 5 and Appendix A).

Table 5: Correlation coefficients found between muscle structure and functional parameters. Significant correlations are highlighted.

	6MWT	30STS	TUG	Jump	Balance	Gait speed	Stair ascent	Stair descent
RF echo intensity	-0.32	-0.53	0.34	-0.50	0.006	-0.61*	-0.27	0.08
VL echo intensity	-0.30	-0.34	0.39	-0.30	0.04	-0.52	-0.37	0.27
BF echo intensity	-0.30	-0.22	0.38	-0.24	0.31	-0.63*	-0.38	-0.14
RF thickness	0.56*	0.41	-0.38	0.27	0.04	0.37	0.10	-0.12
VL thickness	0.30	-0.01	-0.32	-0.01	0.008	0.60*	0.34	-0.05
BF thickness	0.45	0.52	-0.22	0.29	0.24	0.32	-0.08	-0.10
RF pennation angle	-0.04	-0.15	0.03	-0.47	-0.43	-0.46	-0.42	-0.28
VL pennation angle	-0.01	-0.20	0.10	-0.10	0.37	0.16	0.67*	0.21
RF fascicle length	0.41	0.37	-0.19	0.44	0.35	0.34	0.36	0.05
VL fascicle length	0.58*	0.26	-0.68*	0.24	-0.39	0.01	-0.58*	-0.53

RF: rectus femoris; VL: vastus lateralis; BF: biceps femoris; 6MWT: six-minute walk test; 30STS: 30-seconds sit-to-stand test; TUG: timed-up-and-go test.
*Significant correlation at $p<0.05$.

2.4.2 TUG

Significant inverse correlations were found between TUG performance and isometric knee extension torque at 90º (moderate) and 60º (strong) (Figures 1A and 1B), which indicates that the shorter the time, the greater the torque. Additionally, VL fascicle length was inversely related with TUG (Table 5). These results are different from those found in the Chapter 1. Maybe the fact that in Chapter 1 both men and women participated and here the participants were only male can explain these discrepant results. RTD and power were not related (Appendix A) with the TUG.

2.4.3 Six-Minute Walk Test

A greater distance walked in the six-minute walk test (6MWT) was correlated with greater RF thickness and VL fascicle length (moderate) (Table 5), isometric knee extension strength at 90º (strong) (Figure 1C), and eccentric knee extension at 60º.s^{-1} (moderate) (Figure 1D). Power and RTD parameters did not present significant association with 6MWT (Appendix A).

2.4.4 Gait Speed

Isometric, concentric and eccentric torques did not correlated with gait speed, as well as power parameters (Appendix A). There were significant correlations of gait speed with RF and BF echo intensity (inverse and moderate), VL thickness (as in Chapter 1) (Table 5) and isometric knee flexion (30º) RTD at 200 ms (direct and moderate) (Figure 1E). These results indicate that the greater the preferred speed, the better the RF and BF muscle quality and the greater the RF thickness and the RTD.

2.4.5 Stair Ascent

A greater time in the stair ascent test was associated with a greater VL pennation angle and with reduced VL fascicle length (Table 5) and concentric knee extension torque at 60º.s^{-1} (Figure 1F). RTD and power parameters were not significantly correlated (Appendix A).

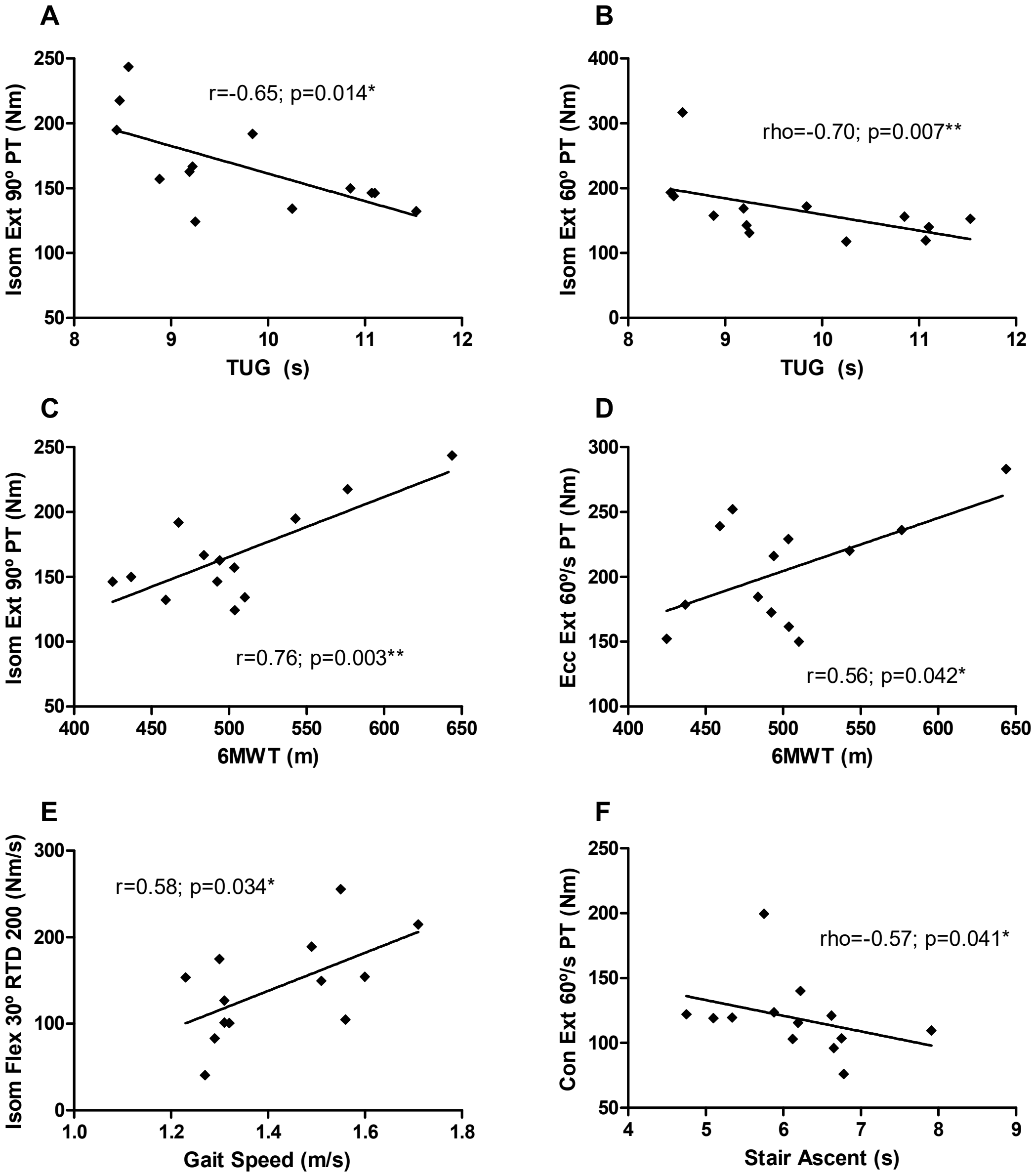

Figure 1. Results for correlation of TUG (A and B), 6MWT (C and D), gait speed (E) and stair ascent (F) with peak torque and RTD. Isom: isometric; Ecc: eccentric; Con: concentric; Ext: extension; Flex: flexion. *Signifcant correlation at $p<0.05$. **Significant correlation at $p<0.01$.

2.4.6 Stair descent

None of the investigated parameters were related with stair descent time (Table 5 and Appendix A).

2.4.7 30-seconds sit-to-stand test (30STS)

Muscle structural parameters were not associated with the number of repetitions in the 30STS (Table 5). On the other hand, it was significantly related with torque, power and RTD parameters. For knee extensors, direct correlation was observed with isometric torque at 90º (strong, Figure 2A), with eccentric torque at 60º.s^{-1} (moderate, Figure 2B), concentric torque at 60º.s^{-1} and 180º.s^{-1} (moderate and strong, Figures 2C and 2E, respectively), power at 60º.s^{-1} and 180º.s^{-1} (strong and moderate, Figures 3A and 3B, respectively) and RTD at 50 ms at 90º (moderate, Figure 3D). Knee flexors concentric torque at both speeds (moderate for 60º.s^{-1} and strong for 180º.s^{-1}, Figures 2D and 2F) and power at 60º.s^{-1} (moderate, Figure 3C) were also correlated with 30STS performance. All of them were direct correlations.

2.4.8 Countermovement Jump

A greater jump height correlated with a greater isometric knee extension strength at 90º (Figure 3E) and knee extension concentric torque and power at 60º.s^{-1} (Figures 3F and 3G, respectively). Structural, RTD and eccentric torque variables were not related with jump height.

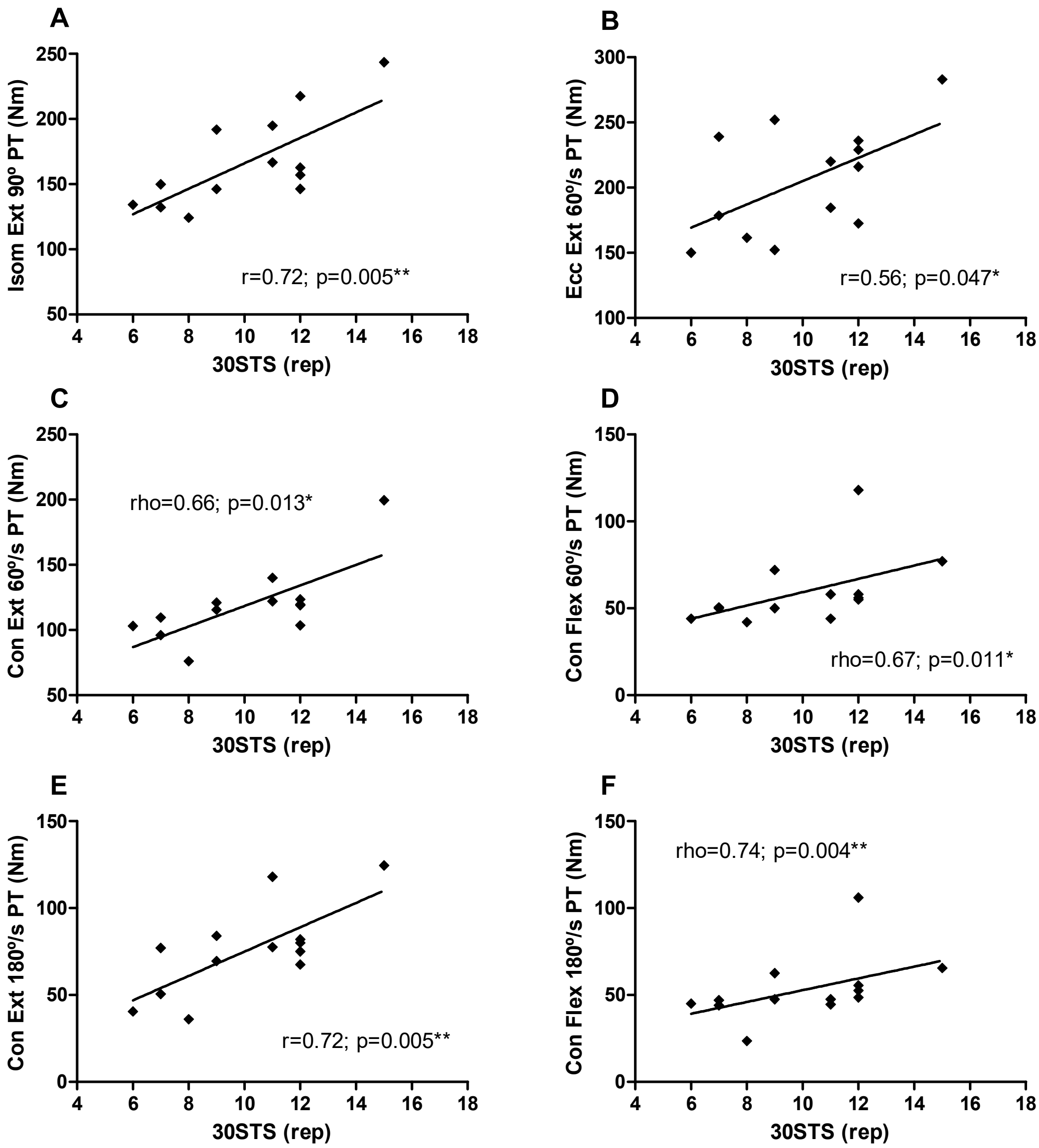

Figure 2. Results for correlation between 30STS and peak torque. Isom: isometric; Ecc: eccentric; Con: concentric; Ext: extension; Flex: flexion. *Signifcant correlation at $p<0.05$. **Significant correlation at $p<0.01$.

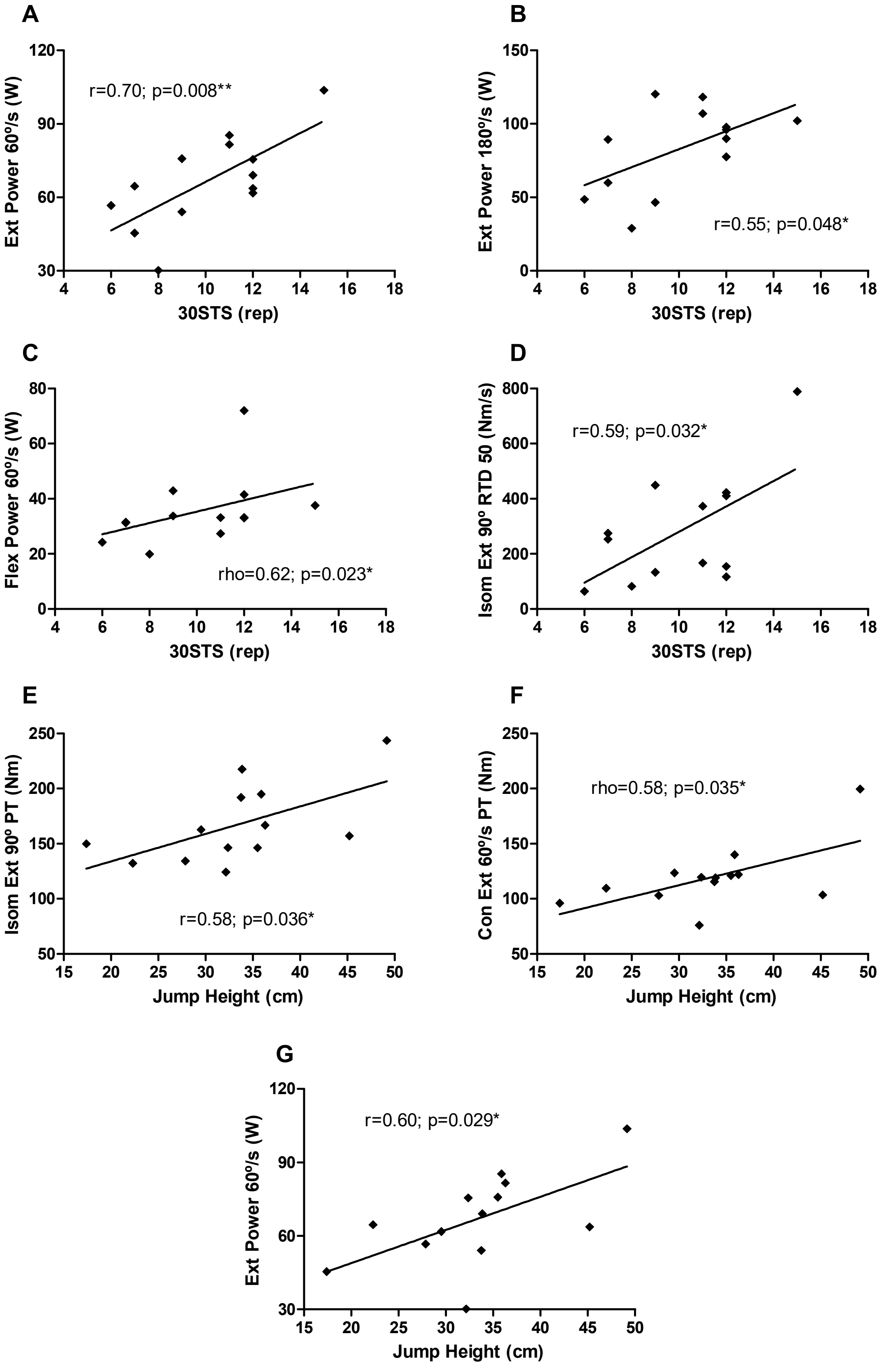

Figure 3. Results for correlation of 30STS and jump height with peak torque, concentric power and RTD. Isom: isometric; Con: concentric; Ext: extension; Flex: flexion. *Significant correlation at $p<0.05$. **Significant correlation at $p<0.01$.

2.5 Discussion

Here our aim was to verify whether knee extensor and flexor muscular parameters might correlate with functional capacity in older men. We found that knee extensors structure (mainly fascicle length) and concentric, followed by isometric and eccentric torques, were the parameters related with functional performance. When the task performance is dependent on power (i.e. 30STS and jump height), power was also significantly correlated. Therefore, a main application of our findings concerns the importance of training knee extensor muscles to improve functionality in the elderly, and we suggest that different contraction types should be considered in the training configuration.

The performance of tasks involving walking (6MWT, TUG and preferred gait speed) seems to depend more on muscle structure than torque characteristics. This suggests that muscular intrinsic adaptations may account more to achieve gains in functionality. Furthermore, knee extensors torque and structure were more associated with walking tasks.

Gait speed is one important parameter to be assessed in the elderly. We found RF and BF echo intensity inversely related to gait speed, and VL thickness directly related, without relationship with strength parameters (torque, power and RTD). A previous study also found a relationship between gait speed and RF echo intensity, but no relation with quadriceps muscle thickness [9]. One possible reason for this result is that our participants were could walk independently, and therefore gait performance may be not significantly dependent on muscle strength. These relations need further investigation in elderly with reduced independence. However, we cannot consider this a limitation in our study, as previous studies considering isometric or dynamic strength also presented controversial results regarding the relationship between preferred gait speed and knee extensors and flexors strength [9, 10, 12-14]. Therefore, we cannot stablish that gait speed is dependent of these muscular parameters, and additional studies are necessary to clarify this point.

Also considering gait performance, we found TUG inversely related with VL fascicle length. Fascicle length is associated with contraction velocity [52], which might help to explain its relation with TUG performance that is basically dependent on gait speed during the task. In this regard, isometric knee extensor torque was also directly related with TUG results. The same occurred for the

6MWT, where greater distances covered during the test were associated with greater VL fascicle length, as well as greater RF thickness. Power and RTD were not related with TUG and 6MWT, which can be relate to the fact that TUG was performed at preferred speed, and 6MWT has a longer duration, not requiring high power and RTD production.

Time in unipodal stance and stepping down stairs were not associated with muscular parameters. Initially, we hypothesized that stair descent would be related to the eccentric torque, but it was not the case. The control of static balance is known to rely more on ankle dorsiflexors, plantar flexors, hip abductors and adductors muscles [53]. It may explain the fact that knee extensors and flexors were not associated with balance performance.

On the other hand, stair ascent performance was associated with greater knee extensor concentric torque, reduced VL pennation angle and greater VL fascicle length. It appears that more sarcomeres in series were more important here than parallel sarcomeres to produce the concentric torque necessary to step up the stairs. However, in a previous study, stair climb power was directly related with knee extensors thickness and VL pennation angle, but not with VL fascicle length [26].

Countermovement jump height was correlated with knee extensors strength and power. It is an expected result due to the specificity of the movement performed. Muscle structure parameters were not related to the jump performance. This is contrary to what was previously seen in another study for quadriceps thickness and VL pennation angle, and in accordance for VL fascicle length [26]. Power in the countermovement jump was also associated with quadriceps echo intensity and thickness in a previous study [44]. These results demonstrate that the relation between jump performance and muscle’s structure remain controversial for older subjects.

Performance in the 30STS was not related to muscle structure. However, correlations with isometric, concentric and eccentric torques, power and RTD were found for both knee extensors and flexors. Sitting on a chair and standing up involve both hip and knee extensors, and eccentric contractions when sitting and concentric contractions when standing up. Therefore, the movement specificity adequately explains the observed correlations with torque production at specific contraction types. Concentric and eccentric knee extensor torque were also related with 30STS previously [54], but isometric was not [44]. As the hamstrings muscles also work to extend the hip, this explains the association of this muscle group with 30STS performance, although this task is mainly performed by the knee extensors than flexors in healthy older subjects [55]. As the subjects were instructed to do the test at maximal speed, aiming to perform the maximal number of complete repetitions during 30 s, it seems natural that power and RTD are correlated with this test performance. RTD is involved with both neural and intrinsic muscle parameters [56], which suggest that rehabilitation programs should include exercises requiring fast muscle activation. Power is the product of muscle force and angular velocity, two important variables necessary for a good performance on the test. Elderly loose force by the parallel sarcomere loss (or atrophy) and contraction velocity by the serial sarcomere loss with aging [8]. Therefore, rehabilitation programs should seek both parallel and serial muscle hypertrophy. Strength exercises performed isometrically with the knee extensors at long muscle length and/or eccentric exercises are important exercise modalities to improve functionality in older adults. Concentric contractions, on the other hand, will focus more in muscle activation, and might produce neural adaptations also needed to respond quickly to daily life stimuli. All these parameters were well correlated with performance at the 30STS test.

Despite the lack of relations between 30STS and muscle structure, previous studies showed significant relations with quadriceps echo intensity [9, 44] and controversial results for quadriceps thickness [9, 44]. Early and late knee extensors RTD evaluated at 60º of knee flexion were associated with 30STS in another study [9]. However, here only the early RTD at 90º of knee flexion was associated with 30STS. This suggests that older subjects able to generate force rapidly when seated (90º of knee flexion) will have a better performance in this test.

2.6 Conclusion

Concentric torque, especially for knee extensors, seems to play an important role for functional performance in the elderly. The significant association between functionality and VL fascicle length and the results for concentric torque suggest that an eccentric training combined with concentric contractions would be more efficient to improve the general functionality in the older adults. Furthermore, our results support the concept that functionality in the elderly cannot be ensured only by one specific modality of exercise or movement to be trained, but programs including multicomponent activities are at a higher chance of effectively improve elderly independence, as several parameters were related with the functional outcomes in the present study. From these results and to investigate if strength trainings utilizing different types of contraction can produce different effects on elder’s functionality and muscle structure and function, in the next chapter (Chapter 3), we will investigate the effects of strength training for older individuals lower limbs considering different types of contraction.

CHAPTER 3 - MUSCULAR AND FUNCTIONAL RESPONSES TO CONCENTRIC AND ECCENTRIC STRENGTH TRAINING IN OLDER ADULTS: A SYSTEMATIC REVIEW

3.1 Abstract

Here we performed a systematic review of controlled trials comparing the effects of concentric and eccentric resistance training, isolated or in combination, on lower extremity muscular and functional performance in older adults (CDR42017075316). Six databases were searched. The outcomes of interest concerned neuromuscular parameters and functional performance. To be included, trials should present 65 years old or older subjects, submitted to concentric and/or eccentric training, performed in isokinetic dynamometer, at least twice a week during 4 weeks, and compare results to a control group or between different contraction type trainings. Quality assessment considered the Cochrane Risk of Bias Tool. The initial search returned 6883 studies, and after eligibility assessment, 4 studies were included. Three of them compared a concentric training with a control group, and one compared groups performing concentric versus eccentric training. All studies focused on knee extensor and flexor muscles, and one focused also on ankle dorsiflexors and plantarflexors. Training programs included 3 sessions/week and lasted 8 to 12 weeks. Concentric training improved strength, power, and muscle antagonist coactivation in comparison to the control group. Between concentric and eccentric trainings, both programs improved knee isometric, concentric and eccentric strength and the self-paced step test, without improvements in gait speed. Muscle structural parameters were not considered in the studies. There is a lack of well-designed randomized controlled trials investigating the effects of isokinetic training for older individuals. The available studies did not identify the training programs' effects on elderly functional capacity, and were focused mainly on neuromuscular parameters.

Keywords: aged, aging, resistance training, muscles, lower extremity.

3.2 Introduction

Life expectancy at 60 years of age is gradually increasing, changing from 18.8 years to 20.5 years from 2000 to 2016 [1]. Aging is accompanied by several adaptations in the musculoskeletal system structure and function. These changes include reduced muscle mass and strength [2, 3], leading to functionality impairments and increased risk of falls in older adults [3].

The importance of muscle strength for the elderly functionality maintenance is well established in the literature [57]. Around the 4^{th} decade of life, muscle strength reduction initiates [4, 5, 7]. Losses in muscle mass have the onset at the age of 25 years, and gradually increase as the age advances [6]. At the age of 80 years, an individual may have up to 40% of muscle loss in comparison to a young adult [6]. These differences are a result from reduced size (hypotrophy) of type II muscle fibers [2], and, to a less extent, from reduced number (atrophy) of both fiber types I and II [6]. However, there are other neuromuscular parameters that determine aging adaptation in the musculoskeletal system, including a decline in the neuromuscular activation capacity, an increased antagonist co-contraction [58], and muscle architecture alterations [8]. Taken together, these adaptations limit functional tasks performance, including those required for daily life independence.

Physical exercise is effective to slow down or reverse skeletal muscle aging adaptations [15, 16], and one of the most advocated strategies to improve elderly's functionality and independence is the resistance training including concentric and eccentric actions [17, 18]. Concentric actions increase pennation angle in the trained muscles compared to eccentric actions [19], which increase fascicle length more than concentric training [19]. However, both concentric and eccentric actions are required during the daily life tasks performance, and, consequently, are functionally important. Activities like rising from a chair, climbing stairs and walking uphill require mainly hip and knee extensors concentric actions. Eccentric contractions are particularly required when sitting on a chair, stair descending, and downhill walking.

The way the training is conducted is also important, with strength exercises being performed in isokinetic dynamometers, body weight bearing exercises, and traditional weight machines. Between these modalities, the isokinetic dynamometer allows for exercise load control [59] at constant angular velocity

[60]. Force production is dependent on contraction velocity, and in free weights and in traditional weight machines angular velocity is not constant and changes along the total range of motion. This does not allow using the maximal muscle potential during the entire joint range of motion [61], for both concentric and the eccentric phases of motion [19].

When designing exercise interventions for the elderly, it is important to have clear information regarding which type of muscle action may result in larger gains, and what are the effects of the different muscle actions (i.e. concentric and eccentric) on neuromuscular and functional performance. However, while previous studies have established the benefits of resistance training, it remains unclear whether differences exists between training programs based on concentric and eccentric actions either administrated isolated or combined. Thus, the aim of the present study was to perform a systematic review of controlled trials that compared the effects either of concentric and eccentric resistance training, isolated or in combination, performed on isokinetic dynamometers, on the lower extremity muscular and functional performance in older adults.

3.3 Materials and Methods

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

3.3.1 Search strategy

Controlled trials indexed in Medline (via Pubmed), CINAHL, SPORTDiscus, PEDro, Cochrane Central, and Embase, published until January 19th 2018, were searched. References lists from the studies included in this review were also searched to find other potential studies to be included in this review.

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 can be found in the Appendix B.

3.3.2 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 4 weeks, with a frequency of 2 or more sessions per week (at least 8 sessions in total) performed in isokinetic dynamometers with angular velocity control. A description of the training characteristics should be available for the study to be included. Studies investigating at least one of the outcomes of interest were included.

Non-randomized or non-controlled controlled trials, studies including hospitalized individuals, and/or individuals with some pathology 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.

3.3.3 Study selection

Results from each database were exported for further analysis of titles and abstracts by two independent authors (ECG, KJVS). 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 author were downloaded and the eligibility criteria were applied for them. Two independent authors (ECG, KJVS) performed full-text analyses, and discrepancies were solved by consensus.

3.3.4 Outcomes

The considered outcomes were: 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 when determining 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 (time to perform the test), balance (static balance, bipodal or unipodal, time to maintain the position or center of pressure displacement), vertical jump (height) and 6-min walking test (distance walked in 6 min).

3.3.5 Quality assessment

Two independent reviewers (ECG, KJVS) 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 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.

3.3.6 Data extraction

Two authors (ECG, KJVS) 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 height), training characteristics (number of sessions, weekly frequency and exercises performed, volume, intensity, movement velocity, sets and repetitions), and 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 only in figures, the first author of each study was contacted to get the raw data.

3.3.7 Data analysis

Data analyses were planned to consider qualitative and quantitative approaches. However, the small number of included studies 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.

3.4 Results

3.4.1 Yield

The initial search returned 6883 studies retrieved from the different databases. Duplicates were removed and, after title and abstract analysis, 339 full-texts were downloaded for analysis. After inclusion and exclusion criteria analysis, 4 studies fulfilled the eligibility criteria for inclusion in this systematic review. The complete process of search and selection of the studies is depicted in the Figure 4.

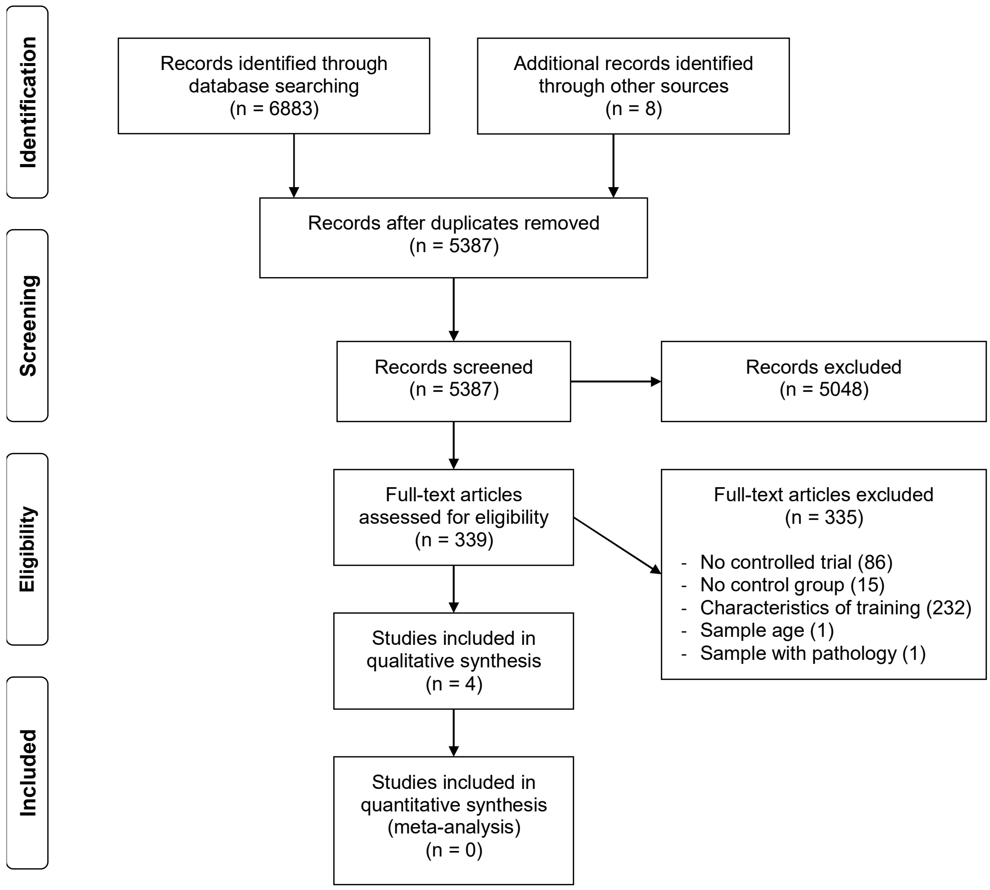

Figure 4. Flowchart of search and selection of the studies included in the systematic review.

3.4.2 Characteristics of the included studies

Table 6 shows the main characteristics of the participants and training programs. All studies included older women [61-64], and two studies included only women [62, 63]. The mean participants' age was 69.7 years. Three studies compared a concentric training with a control group [61-63] and one study compared groups performing concentric versus an eccentric training [64]. All studies considered a weekly frequency of 3 sessions, with a total program duration ranging from eight to twelve weeks [61-64], focused on knee extensors and flexors muscles. Ankle dorsiflexors and plantarflexors muscles were considered in one study [63].

3.4.3 Training Effects

Table 7 describes the results and outcomes from each study. Concentric training improved strength, power, rate of torque development, and muscle activation in comparison to control groups [61-63]. Functional parameters were not considered in the studies. Concentric and eccentric trainings improved isometric, concentric and eccentric strength and the self-paced step test (stair test) without improvements in gait speed [64]. Muscle structural parameters (echo intensity, thickness, pennation angle and fascicle length) were not outcomes of interest in the selected studies.

Table 6. Main characteristics of participants and training programs in the included studies.

Study	Participants			Characteristics of training							
	Groups	Age	Number/ Gender	Weekly frequency	Program duration	Muscular group	Lower limb	Intensity (%)	Velocity (º.s^{-1})	Range of motion	Number of series x repetitions
Laroche et al., 2008 [62]	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	90º to 180º	3x8 (each velocity)
Malliou et al., 2003 [61]	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 [63]	Control Concentric HS Concentric LS	69.01±1.75 68.37±1.42 68.76±1.62	7 F 9 F 8 F	3	12 weeks	knee extensors and flexors; ankle plantar flexors 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 [64]	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

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

Table 7. Outcomes measured and results from each included study.

Study	Outcome	Pre		Post		Effect of time		
		Control (mean±SE)	Concentric (mean±SE)	Control (mean±SE)	Concentric (mean±SE)	Control	Concentric	
Laroche et al., 2008 [62]	Knee extensor isometric peak torque (105º) ($N.m.kg^{-1}$)	1.25±0.12	1.57±0.13	1.32±0.13	1.68±0.13	(~) P>0.05; ES=0.17	(↑) P=0.03; ES=0.25	
	Rate of torque development (105º) ($N.m.s^{-1}.kg^{-1}$)	6.24±0.8	7.17±0.89	6.73±0.73	7.1±0.89	(~) P>0.05; ES=0.19	(~) P>0.05; ES=-0.02	
	Antagonist coactivation (%pEMG)	22.27±2.36	24.28±2.88	25.65±3.86	21.24±1.88	(~) P>0.05; ES=0.32	(↓) P=0.02; ES=-0.39	
	Onset EMG amplitude (%pEMG)	92.71±3.6	85.45±4.33	86.14±3.69	79.68±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 [61]		Control (mean±SD)	Concentric (mean±SD)	Control (mean±SD)	Concentric (mean±SD)	Control	Concentric	
	Knee extensors concentric peak torque 60º.s^{-1} (Nm)	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 180º.s^{-1} (Nm)	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 [63]						Control	HS	LS
	Knee extension average power 60º.s^{-1} (W)	*Data were presented only as Figures.		*Data were presented only as Figures.		(~) P>0.05	(~) P>0.05	(~) P>0.05
	Knee extension average power 180º.s^{-1} (W)					(~) P>0.05	(↑) Δ25.96±5.06 P=0.0007	(~) P>0.05
	Knee extension average power 300º.s^{-1} (W)					(~) P>0.05	(↑) Δ32.49±6.34 P=0.0004	(~) P>0.05
	Knee flexion average power 60º.s^{-1}s (W)					(~) P>0.05	(~) P>0.05	(~) P>0.05
	Knee flexion average power 180º.s^{-1} (W)					(~) P>0.05	(~) P>0.05	(~) P>0.05

	Knee flexion average power 300º.s^{-1} (W)					(~) P>0.05	(~) P>0.05	(~) P>0.05
	Ankle dorsiflexion average power 60º.s^{-1} (W)					(~) P>0.05	(↑) Δ2.51±0.55 p=0.0036	(↑) Δ3.50±0.36 p=0.0003
	Ankle dorsiflexion average power 180º.s^{-1} (W)					(~) P>0.05	(↑) Δ6.31±1.06 p=0.0001	(↑) Δ6.66±1.01 p=0.0001
	Ankle dorsiflexion average power 300º.s^{-1} (W)					(~) P>0.05	(↑) Δ5.65±0.82 p=0.0001	(↑) Δ7.60±0.65 p=0.0001
	Ankle plantar flexion average power 60º.s^{-1} (W)					(~) P>0.05	(~) P>0.05	(↑) Δ9.12±2.63 p=0.0132
	Ankle plantar flexion average power 180º.s^{-1} (W)					(~) P>0.05	(~) P>0.05	(↑) Δ12.47±3.53 p=0.0310
	Ankle plantar flexion average power 300º.s^{-1} (W)					(~) P>0.05	(~) P>0.05	(~) P>0.05

		Concentric (mean±SD)	Eccentric (mean±SD)	Concentric (mean±SD)	Eccentric (mean±SD)	Concentric	Eccentric
Symons et al., 2005 [64]	Knee extensors peak isometric torque (90º)	130.6±54	142±39.8	151.8±61.2	176±44.7	(↑) P<0.01; Δ%: 17.3	(↑) P<0.01; Δ%: 25.5
	Knee extensors peak concentric torque (90º.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 (-90º.s^{-1})	161.9±62.6	168.5±40	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	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%

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.

3.4.4 Quality assessment

Two reviewers performed the methodological quality assessment, and results are presented in the Table 8. It is possible to observe that none of the included studies presents a low risk of bias in all items assessed. In addition, two studies present the majority of the items assessed with low risk of bias and two studies present most of the items with high risk or unclear.

Table 8. Quality assessment.

	Laroche et al., 2008 [62]	Malliou et al., 2003 [61]	Signorile et al., 2002 [63]	Symons et al., 2005 [64]
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

3.5 Discussion

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. We considered studies that, among other characteristics, conducted the training using an isokinetic dynamometer. Our main findings concern a small number of controlled trials addressing the effects of isokinetic training on elderly muscular and functional performances, with most of the items in the quality assessment considered with low risk of bias in two studies and with a greater risk of bias in two other studies. A positive effect on knee muscle performance and a lack of functional performance analysis were common observations among the included studies.

One could argue that isokinetic training is hard to be applied in the general population due to the need for the specific instrumentation. However, when it comes to determining the training adaptations, such machinery is fundamental to identify the responses to the different stimuli from concentric and eccentric muscle actions. Among the advantages of this type of equipment is the safe control of the load [59] (which is important for older individuals), the constant angular velocity [60], which controls the effect of velocity on force production, as demonstrated by the force-velocity curve, and allows to accommodate the maximal muscle potential along the entire range of motion [61], and the fact that the load can be set separately to elicit similar effort for both concentric and the eccentric phases of the movements [19], once that eccentric contractions produce greater strength, compared to the concentric.

Based in the included studies, it is still not clear 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. Most of them did not consider the muscular and functional performances together, and many studies available in the literature were limited due to the lack of a control group or other comparative group and, because of this, were not included in the present review.

Concentric training was the most popular configuration of isokinetic training among the included studies. Isokinetic training including only concentric actions (knee extensors and flexors) compared with a control group was performed in three of the four studies in the present review [61-63]. All studies reported improvement in neuromuscular parameters, but none considered functional capacity assessment in the trained elderly. The training programs improved knee extensor isometric [62] and concentric [61] torques, and reduced antagonist coactivation [62]. The reduced coactivation may benefit movement coordination [59], leading to more efficient movements during activities of daily life (e.g. rising from a chair, climbing stairs). Although power is an important functionality component in the older adult, no modifications in the rate of torque development and neuromuscular activation [62] were observed in response to training, despite the adopted training velocities.

Signorile et al [63] developed a concentric training program at two different velocities (knee: 60 and 270º/s; ankle: 60 and 180º/s), and found that knee flexors power had no improvements at the assessed velocities (60º/s, 180º/s and 300º/s). Knee extensors power did not change for the lower-velocity training group. Conversely, high-velocity training improved knee extensor power at the two greater angular velocities (180º/s and 300°/s). The use of high-velocity training can be a strategy for improving rapid reaction to perturbation, which is important during daily life for the older individuals, in situations that demand this ability (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 decreased with aging.

When ankle muscles were trained, there were improvements in dorsiflexion torque at the different tested velocities, regardless of the training velocity [63]. Results were different for ankle plantar flexors, in which the high-velocity training did not improve and low-velocity training benefit the power performance at lower velocities, showing the specificity of training velocity.

Trainings focusing on ankle muscles are also important, once that, for example, the capacity to activate the dorsiflexors muscles, generating a greater dorsiflexion during the swing phase of gait leads to a reduced risk of toe contact with obstacles [65], preventing trips and subsequent falls. Moreover, ankle plantar flexor strength is important during the propulsion phase of walking.

Concentric and eccentric contractions present several differences [66]. Hence, the specific contraction type used in the training can leads to different adaptations in the muscle's structure [66]. Concentric contractions lead to greater improvements in the pennation angle, due to the addition of sarcomeres in parallel [19]. On the other hand, eccentric actions lead to greater improvements in fascicle length, due to the addition of sarcomeres in-series sarcomeres [19]. However, the included studies did not investigate muscle structural parameters.

Only one study compared the effects of concentric versus eccentric training performed in isokinetic dynamometer on muscular and functional parameters of older adults [64]. In this case, both trainings improved knee extensors strength (isometric, concentric and eccentric strength), knee extensors concentric power (which was higher in the concentric than in eccentric group), and performance in self-paced step test [64]. 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. One practical application of this study is the identification of which type of muscle action is more impaired in the older adult, and suggest the choice for the equivalent training. Furthermore, the results suggest that if both muscle actions need attention, a combined training could be more adequate.

Gait speed did not change in response to different trainings, most likely because only knee extensors were trained. Hip extensors and ankle plantar flexors have significant correlation with preferred gait speed, but the knee extensors do not [13], which suggest that older adults strength training should also focus on hip and ankle muscles.

All studies reported neuromuscular parameters improvement, but only one considered functional capacity assessment [64], and none considered muscle structure. Structural parameters can elucidate the strength gain mechanisms, and therefore need to be investigated.

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

From the present review included studies, it is possible to observe that all training programs improve lower limb strength, but the improvements are dependent on the training velocity, trained muscular groups, and muscle action. 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 the aging process. For example, training programs with different angular velocities could improve the capacity to perform daily tasks that needs slow or rapid movements, leading to the maintenance of older adults' physical independence. Additionally, if older people have impairment on a specific task, physicians should use the training modality that will be more helpful for that impairment (with specific characteristics of velocity, load, muscular groups and contraction type). Moreover, if there is a global difficulty, more comprehensive trainings could be more efficient (combining two velocities, for example).

3.6 Conclusions

There is a lack of controlled trials investigating the effects of isokinetic training on neuromuscular and functional parameters in older adults. Similar effects of concentric and eccentric training were described by one study. Positive effects of concentric training were consistent across different studies and only one study addressed eccentric training effects. A common characteristic among the studies is the lack of consideration to the effects of different training configurations on functional tasks performance related to independence in the elderly.

There is a need for controlled trials with high methodological quality comparing effects of concentric and eccentric training programs to establish their effects on strength, rate of torque development, muscle structure and muscular activation for older adults, considering a higher methodological quality to avoid bias.

Based on the results found in Chapters 1 to 3, and aiming to fill this gap in the literature (lack of controlled trials with high methodological quality), in the next chapter (Chapter 4) we present the results of a randomized controlled trial, which compares the effects of two types of strength training performed on an isokinetic dynamometer for older individuals. One of them considered only concentric contractions and the other combined both concentric and eccentric contractions for knee extensors and flexors.

CHAPTER 4 - EFFECTS OF CONCENTRIC VERSUS CONCENTRIC-ECCENTRIC RESISTANCE TRAINING FOR OLDER MEN: A RANDOMIZED CONTROLLED TRIAL

4.1 Background and Aims

As demonstrated in the systematic review presented in the previous chapter, there is a lack of controlled trials for older individuals comparing the effects of lower limb concentric and eccentric trainings performed in isokinetic dynamometers. In addition, determining the training effects on functional parameters and on muscle structural outcomes is fundamental for an adequate clinical practice.

The studies included in the review showed positive results for concentric training [61-63], but there were similar effects of concentric and eccentric training analyzed in the single study that compared these two trainings [64]. Considering that both types of muscular actions (concentric and eccentric) are required during daily life tasks, one can expect that a training that combines these two types of contraction can be more effective for muscular and functional parameters improvements.

Therefore, the aim of the present randomized controlled trial is to determine the effects of a concentric versus a concentric-eccentric knee extensors and flexors training program for older men. Our hypothesis is that the concentric-eccentric training will produce greater improvements on muscular and functional parameters. Specifically, in the present chapter, the aims are to present the methodology utilized for the subjects' assessments and trainings, and to present descriptive preliminary results of the randomized controlled trial, that is still ongoing. An important note is that these experiments are currently in the final phase. Therefore, we opted for including a preliminary report here that will follow up with the paper publication in the near future.

4.2 Methods

4.2.1 Participants

Participated in this study older men (65 years or older). The sample size was estimated by G*Power (3.1.9.2, Germany), based on an effect size of 0.4, an alfa level of 0.05, and power of 0.80. It showed a minimum of 18 participants for each group. Before starting the tests, all participants received detailed explanation about the aims and the procedures of the study, and signed an informed consent form. The local institution ethics committee approved this research, according to the Declaration of Helsinki (IRB 2.034.508). Inclusion criteria were not having auditory, vestibular, visual and/or neuromusculoskeletal severe impairments, not reporting pain in the lower limbs, not being systematically enrolled in physical exercise, and not presenting severe cognitive impairments (mean score in the Mini Mental State Examination - MMSE was 27.9±1.9, above the 23 cutoff point [28]).

4.2.2 Experimental design

This study is a randomized controlled trial (NCT03206580), with the purpose of determining the effects of two types of strength training on muscular parameters and functionality of older adults. The evaluator was blinded for the subjects' group. The experimental design can be seen in Figure 5.

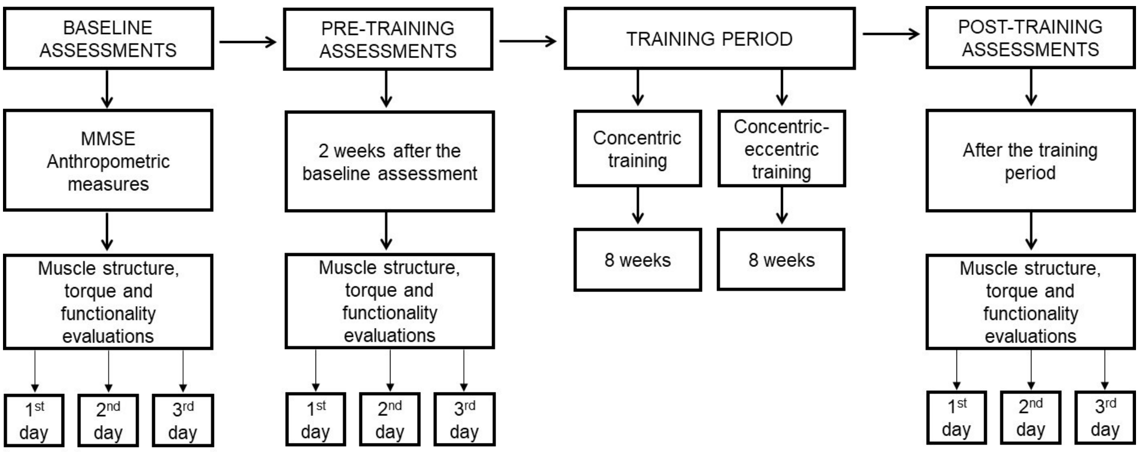

Figure 5. Experimental design.

As shown in Figure 5, assessments were performed in three separate days (with at least 72 h of interval between sessions for the baseline assessments and

48h for pre and post evaluations). On the first day, they answered the MMSE, their anthropometric measures (body mass, height, thigh length and skinfolds) were determined, the echo intensity and muscle architecture (i.e. structural muscular parameters) were assessed, and they performed two or three of the eight functional tests (i.e. functional assessment battery). Additionally, a familiarization with the isometric, concentric and eccentric contractions was performed on the isokinetic dynamometer. On the second day, they performed two or three of the functional tests and the isometric and concentric torque evaluations or the eccentric torque tests (i.e. torque assessment). Finally, on the third day, the remaining functional and torque tests were performed.

Functional tests were divided in three blocks (one block for each day), randomized for each participant. The type of strength tests was also randomized (concentric and isometric; or eccentric only), as well as the muscular group and the lower limb assessed first in each day. All randomizations were done using a sequence generated by the website Randomization.com.

4.2.3 Randomization

Subjects were randomly allocated for the concentric group (CON) or for the concentric-eccentric training group (CON-ECC), following a sequence generated by the website Randomization.com. The complete recruitment and allocation flowchart of all subjects is presented in Figure 6.

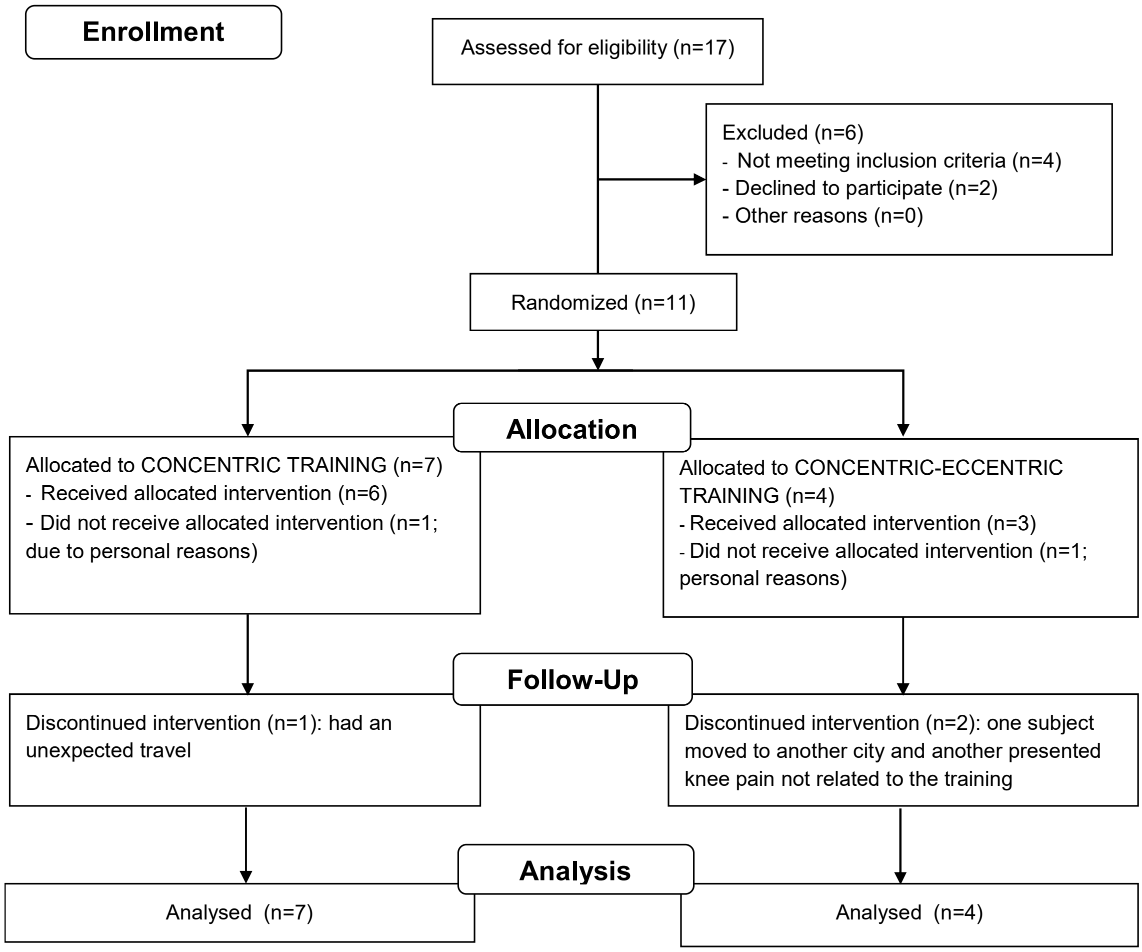

Figure 6. Flowchart of the study.

4.2.4 Training

For both groups, training was performed bilaterally for knee extensors and flexors on an isokinetic dynamometer (Biodex System 3 Pro, Biodex Medical System, USA). Participants were positioned and firmly strapped on the dynamometer according to the manufacturer's recommendations for knee flexion and extension.

The training program lasted 8 weeks, and was performed biweekly, with at least 72h interval between sessions. On each day, subjects warmed-up through two series of ten repetitions of concentric knee extensions and flexions at an angular velocity of $90^{o}.s^{-1}$ and then performed the specific contractions for each training group.

The range of motion utilized was of 70º (from 90º to 20º of knee extension; 0º=full knee extension) and the training velocity was set for $60^{o}.s^{-1}$. The training intensity was set at 70% of the maximal concentric and eccentric contractions.

For the training weeks 1 and 2, the values of the pre training assessments were used to set the intensity. Subjects were re-evaluated every two weeks to re-adjust the training intensity according to the torque capacity changes. Training intensity was controlled during the session through visual feedback set at the dynamometer display.

Training volume progressed every two training weeks, and was matched for both training groups. A detailed volume progression is described in Table 4.1, for each group separately. A 2-min interval was observed between the series.

Table 9. Volume progression for the concentric and for the concentric-eccentric training groups.

CONCENTRIC TRAINING					
Week	Series		Repetitions		Total volume
	Flex	Ext	Flex	Ext	
1-2	2	2	10	10	40
3-4	3	3	9	9	54
5-6	3	3	12	12	72
7-8	4	4	12	12	96

CONCENTRIC-ECCENTRIC TRAINING									
Weeks	Series				Repetitions				Total volume
	Conc Flex	Ecc Flex	Conc Ext	Ecc Ext	Conc Flex	Ecc Flex	Conc Ext	Ecc Ext	
1-2	2	2	2	2	5	5	5	5	40
3-4	2	2	2	2	7	7	7	7	56
5-6	3	3	3	3	6	6	6	6	72
7-8	4	4	4	4	6	6	6	6	96

Ext: extension; Flex: flexion.

4.2.5 Functional capacity

The study functional tests battery evaluated different aspects of functionality in the daily life context, and were selected due to their easy application in different settings, including the clinical setting. A 1-min rest interval between the trials was considered for each test.

Six-Minute Walk Test (6MWT) – Participants were instructed to walk at their maximal pace along a 30 m long flat walkway (delimited with cones) during six minutes. Time was registered for one trial, and the distance, in meters, measured.

30-seconds sit-to-stand (30STS) – A standardized chair (44 cm height) with backrest and without armrests, placed against a wall, was utilized [20]. Participants were instructed to do the test at maximal speed, aiming to perform the maximal number of complete repetitions during 30 s (registered with a stopwatch), with their arms crossed in front of the chest. Two trials were performed, and the maximal number of repetitions was used for analysis.

Countermovement jump – Participants initiated at standing position, feet at shoulder's width and hands at the waist. Kinematic data was collected at 30 Hz using a digital camera (Sony 16.1 MP), positioned at the sagittal plane. The movement of a marker positioned at the participant's greater trochanter was used to determine the jump height. Three trials were performed, and the best value was used for analysis. Data were analyzed through the software Kinovea (version 0.8.15).

Timed Up and Go (TUG) - Participants were asked to rise from a standardized chair (with backrest and without armrests; height of 44 cm) without using the arms, to walk 3 m, turn around a cone, return and sit down again [35]. Participants were oriented to do the task at comfortable speed. Two trials were performed and the best time (registered with a stopwatch) was used for subsequent analysis.

Balance – The unipodal static balance was evaluated bilaterally (two trials for each lower limb). Participants were asked to maintain the position (hip at anatomical position with one knee flexed) during 30 s, a time window used for fall risk screening [51]. The time the task was sustained (initial position, without touching the foot of the lower limb with the knee flexed on the ground) was registered up to 30 s. Two digital cameras (placed at sagittal and frontal planes) registered the task for subsequent analysis of the time the participant maintained the balance. The average of the best performance from each lower limb was used in the analysis.

Gait speed – Participants walked at preferred pace along a flat walkway 10 m long, delimited with two cones. They started 1 m before the walkway and stopped 1 m after. Two trials were performed and the best was considered for subsequent analysis. Time was registered with a stopwatch and the average speed was determined.

Stair ascent – The time, registered with a stopwatch, to step up 10 stairs as fast as possible was registered. The best value of two trials was used for analysis.

Stair descent – The time, registered with a stopwatch, to step down 10 stairs as fast as possible was registered. The best value of two trials was used for analysis.

4.2.6 Peak torque

Knee flexors and extensors maximal isometric, concentric and eccentric torques were assessed bilaterally using an isokinetic dynamometer (Biodex System 3 Pro, Biodex Medical System, USA). Participants were positioned and firmly strapped on the dynamometer according to the manufacturer's recommendations for knee flexion and extension evaluations. They were verbally encouraged to perform their maximal effort at maximal speed along the total range of motion during the tests. Before the evaluations, participants completed a warm-up consisting of two series of ten submaximal concentric repetitions each at 90º.s^{-1}. A 2-min interval was observed between contraction sets. The peak torque was considered for subsequent analysis. Data presented here is a mean of both right and left lower limbs.

Isometric contractions lasted 5 seconds each and three trials were performed at two different positions for each muscular group: knee flexors at 30º and 90º, and knee extensors at 60º and 90º of knee flexion, respectively (0º=full extension). Knee flexion-extension concentric contractions were performed at 60º.s^{-1} and 180º.s^{-1}. Eccentric contractions were performed separately for each muscular group at 60º.s^{-1} and 120º.s^{-1}. Two series of 3 repetitions were performed at each speed, with a range of motion of 70º (90º-20º). All peak torque values were normalized to the participant's body mass.

4.2.7 Power

Concentric power was determined during the maximal concentric tests at 60º.s^{-1} and 180º.s^{-1} for knee flexion and knee extension, and are presented as the mean of both lower limbs results. Power values were normalized to the subject's body mass.

4.2.8 Rate of torque development (RTD)

RTD was determined bilaterally during the maximal isometric voluntary contractions. It was calculated for the first 50 ms and 200 ms (representing the early and late phases of torque production) after the onset of the isometric contraction (when the torque was equal or greater than 5% of peak torque), using the equation $\Delta torque.\Delta time^{-1}$. RTD was determined for the trials where the peak torque occurred for each lower limb, and the mean value of both was considered for subsequent analysis. RTD was normalized to the subject's body mass.

4.2.9 Muscle architecture and muscle echo intensity

Thickness, pennation angle, fascicle length and echo intensity of the rectus femoris (RF), vastus lateralis (VL) and biceps femoris (BF) muscles were measured at rest using a B-mode ultrasound equipment (SSD 4000; Aloka Inc., Tokyo, Japan), with a linear array probe (60 mm, 7.5 MHz). The probe was coated with water-soluble transmission gel to improve acoustic contact. The probe was positioned parallel to the muscle fascicles and transverse to them in the architecture and echo intensity images, respectively. Scans were taken following locations described elsewhere [29] and the sites of measure were mapped, ensuring that the images were taken at the same site on the different moments (baseline, pre and post-training). Participants were instructed to lie down and relax. Three images for each analysis (architecture and echo intensity) were obtained from each muscle, always by the same researcher. Data were collected bilaterally, and the mean of three images from each lower limb was utilized for subsequent analysis. Images were analyzed in the Image J software (National Institute of Health, USA).

Echo intensity was determined by mean gray scale analysis and expressed in arbitrary units between 0 (black) and 255 (white). Region of interest was selected including as much as possible muscle area, avoiding bone and surrounding fascia [9]. Muscle thickness was determined as the mean distance between the superficial and deep muscle aponeuroses, which were measured at five sites along the image [30]. Pennation angle was determined for each image using the best fascicle, and calculated as the angle between the muscle deep aponeurosis and the fascicle [30]. Fascicle length was determined as the length of the fascicular path between the superficial and deep aponeuroses [30], and was normalized to thigh length. When greater than the probe surface, fascicle length was calculated through extrapolation and trigonometric function [31].

4.2.10 Statistical analysis

Data are presented as mean ± standard deviation, and comparisons between each moment for each group are presented as delta values to represent the percent change with respect to the baseline and pre assessments. Data from those subjects lost during the study were considered through an intention-to-treat analysis using the last observation carried forward method.

4.3 Preliminary Descriptive Results

Until now, 11 older men completed the study protocol (73.5±5 years of age; body mass of 84.5±11 kg; height of 1.7±0.1 m; body fat component of 26.9±5%). Table 10 presents the study participants' characteristics included in this preliminary report, for each training group. Preliminary descriptive results of the study outcomes are presented in Figures 7-14. Data are presented separately for each training group, with delta values representing the percentage difference between the baseline and pre-training evaluations, and between the assessments in pre- and post-training period. When the assessments were collected bilaterally, the mean value of both lower limbs was used for analysis.

Table 10. Baseline characteristics (mean ± SD) of the participants included in the study.

	CON (n=7)	CON-ECC (n=4)
Age (years)	73 ± 6	73 ± 4
Body mass (kg)	83 ± 10	87 ± 16
Height (m)	1.7 ± 0.04	1.7 ± 0.1
Body fat (%)	26.8 ± 4.3	27 ± 6.8

CON = Concentric training group; CON-ECC = Concentric-eccentric training group.

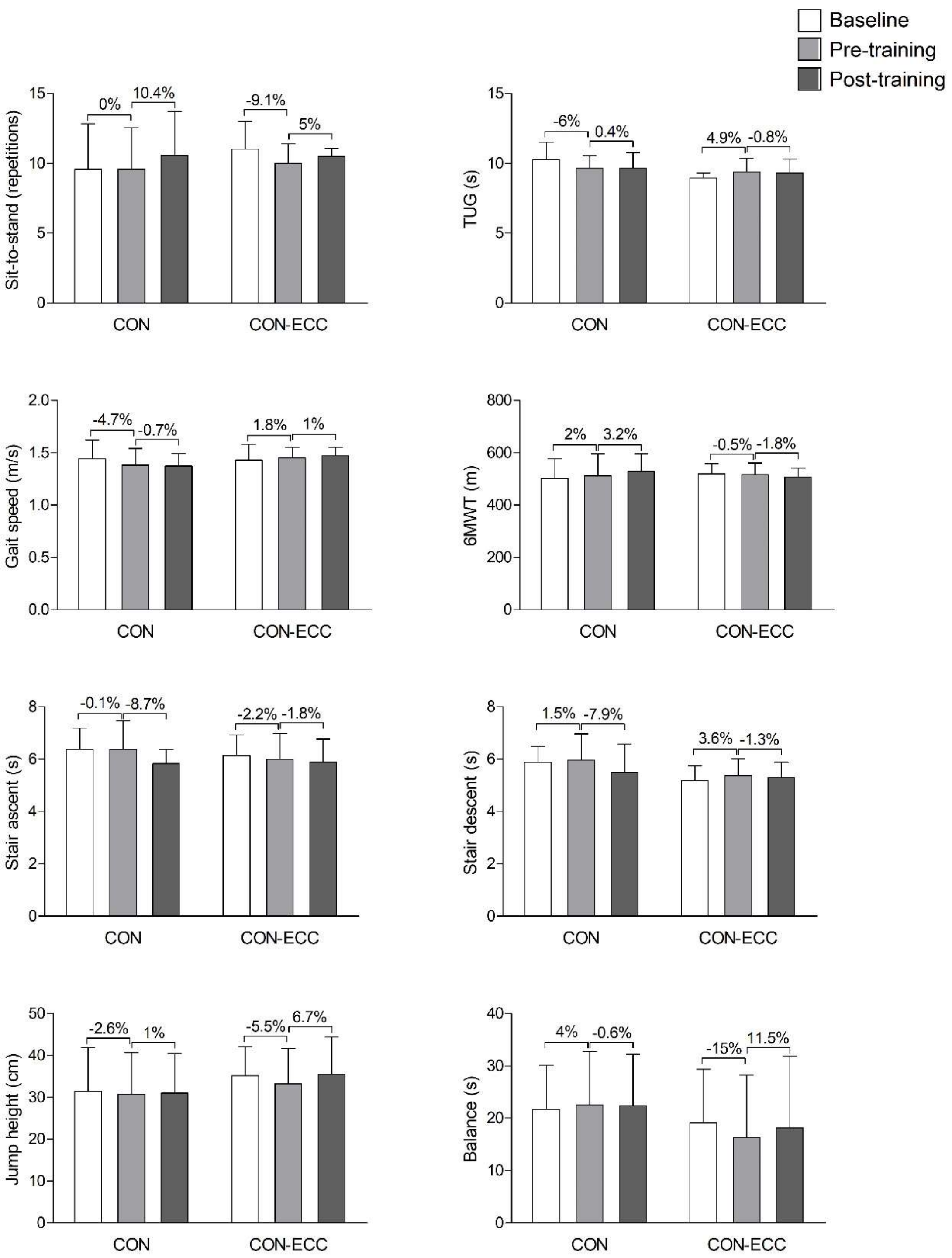

Figure 7. Results for functional capacity.

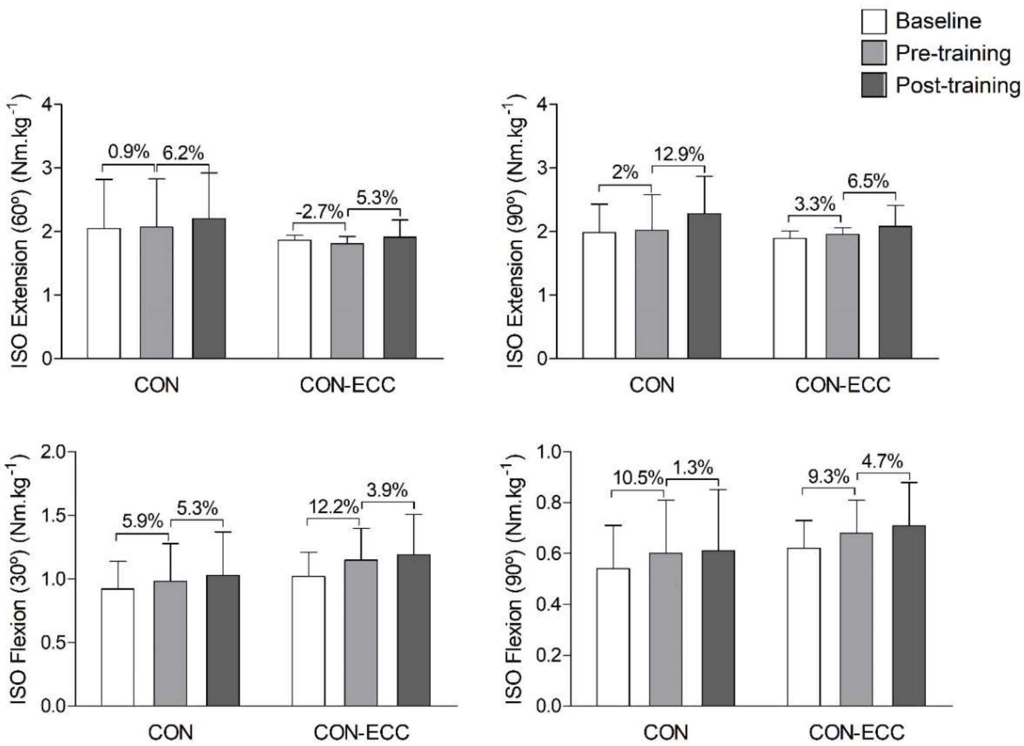

Figure 8. Results for isometric torque. ISO: isometric; CON: concentric; CON-ECC: concentric-eccentric.

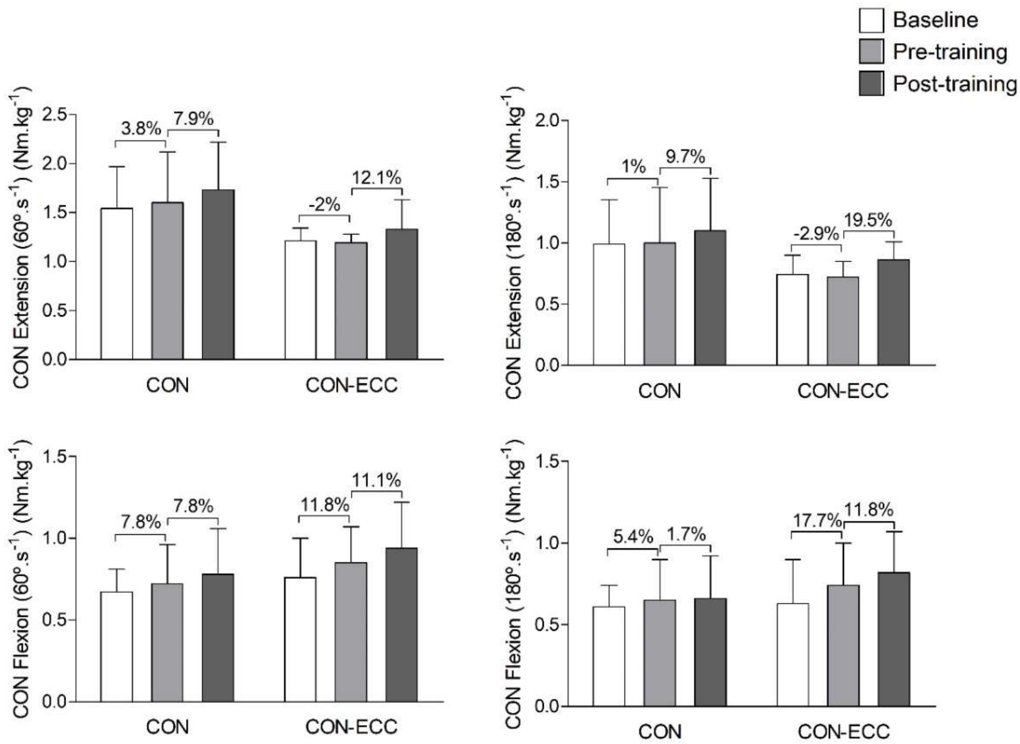

Figure 9. Results for concentric torque. CON: concentric; CON-ECC: concentric-eccentric.

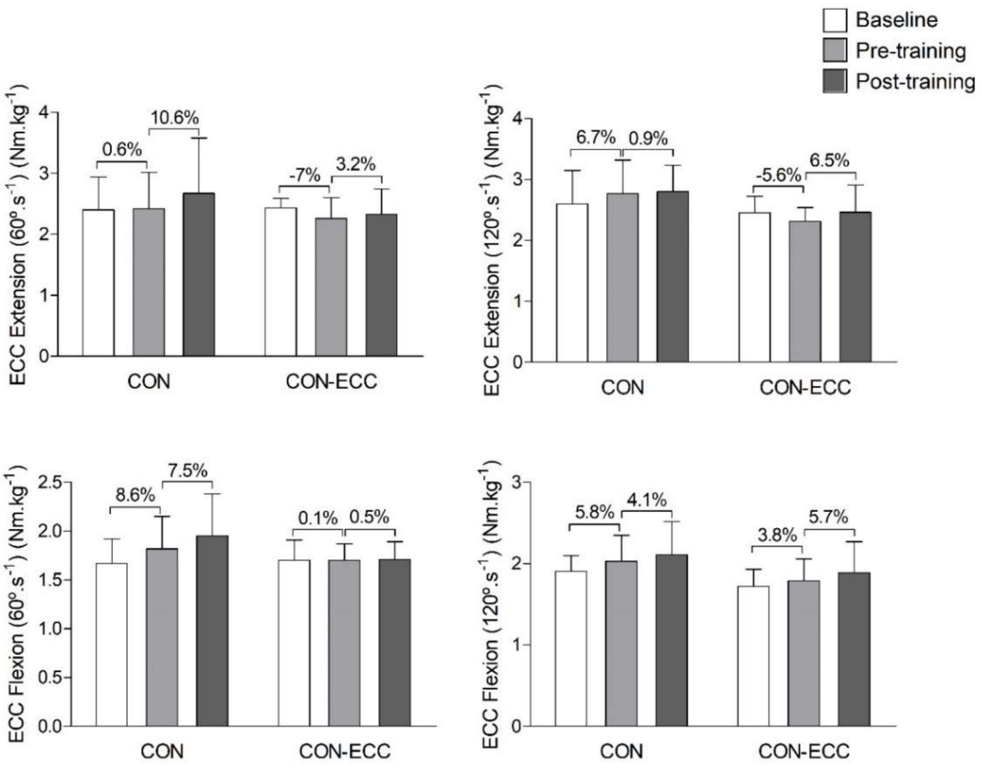

Figure 10. Results for eccentric torque. ECC: eccentric CON: concentric; CON-ECC: concentric-eccentric.

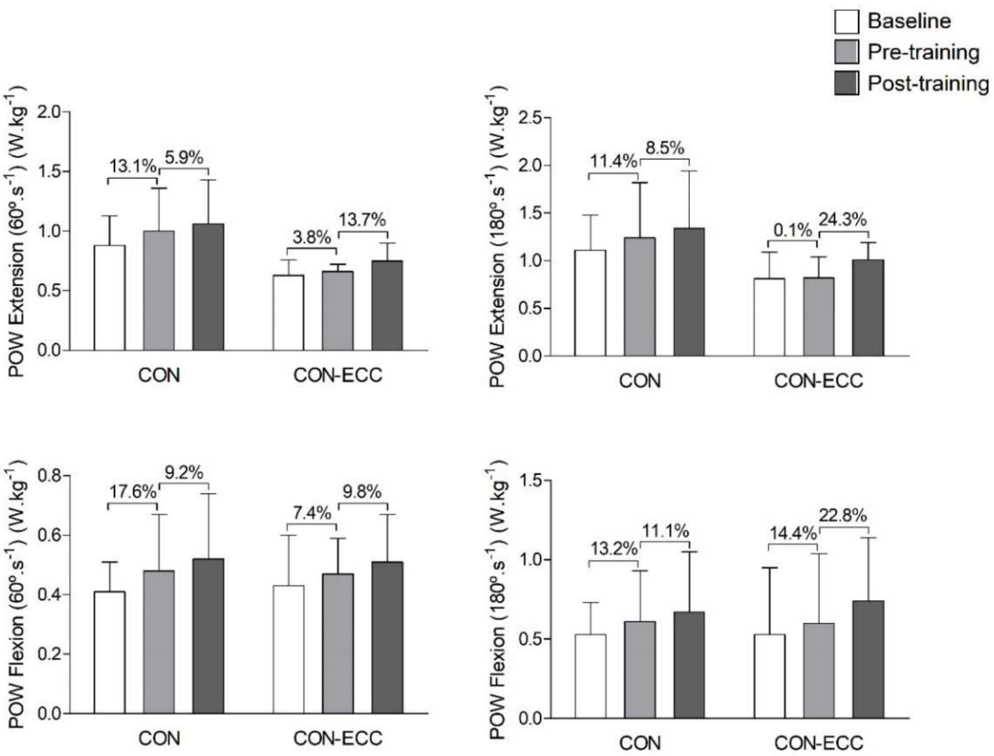

Figure 11. Results for concentric power. POW: power CON: concentric; CON-ECC: concentric-eccentric.

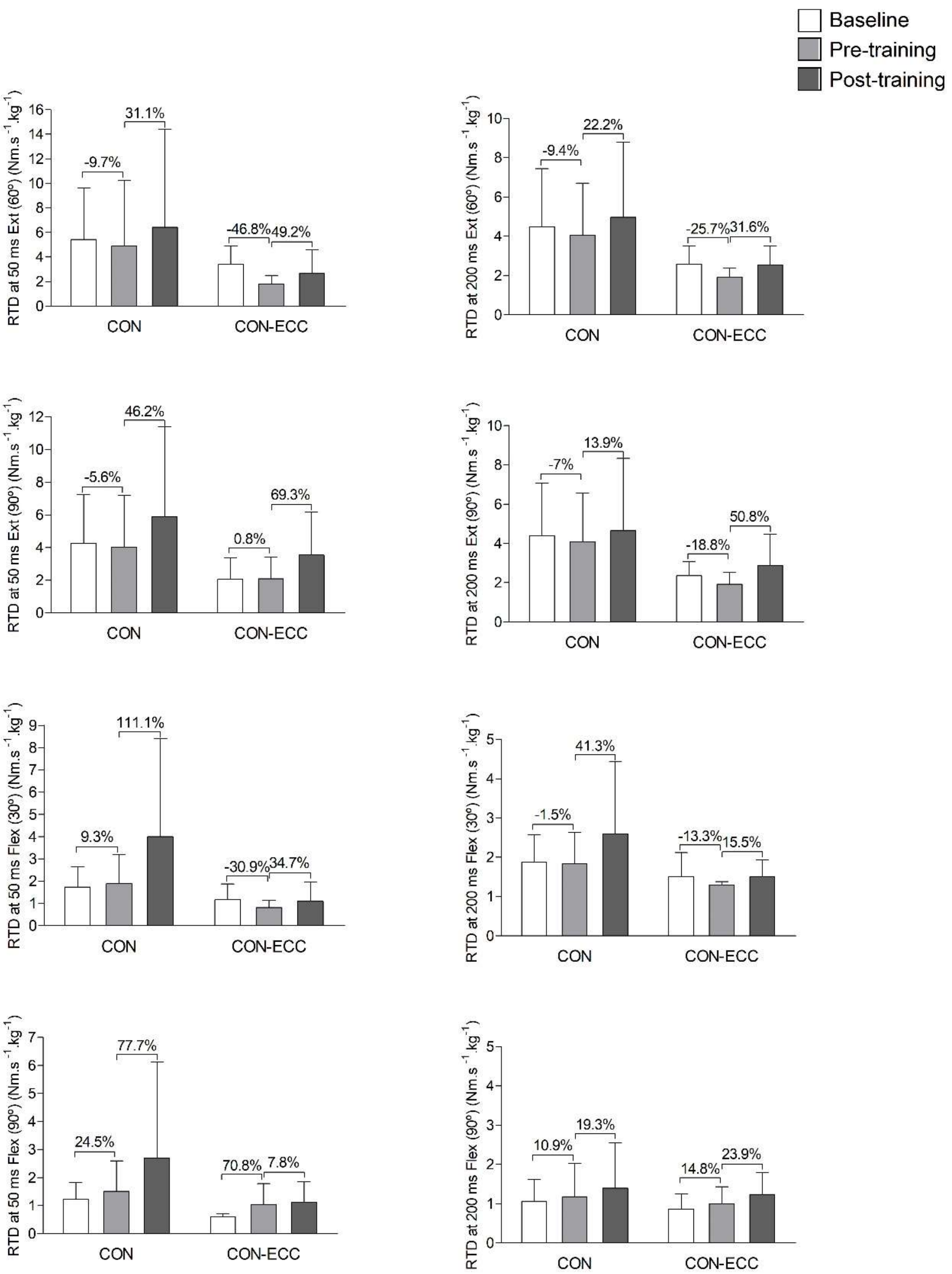

Figure 12. Results for rate of torque development (RTD). Flex: flexion; Ext: extension; CON: concentric; CON-ECC: concentric-eccentric.

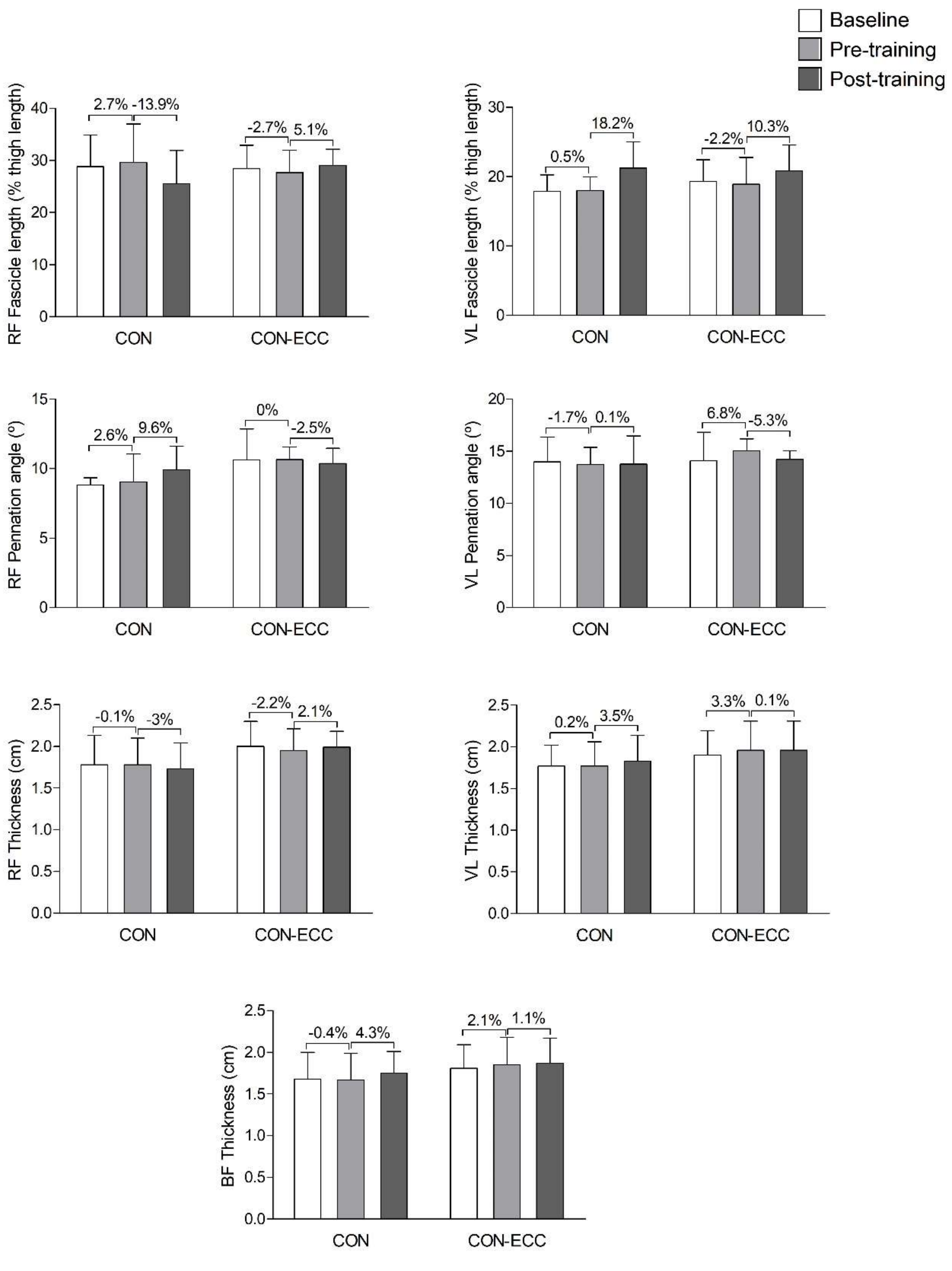

Figure 13. Results for muscle architecture parameters. RF: rectus femoris; VL: vastus lateralis; BF: biceps femoris; CON: concentric; CON-ECC: concentric-eccentric.

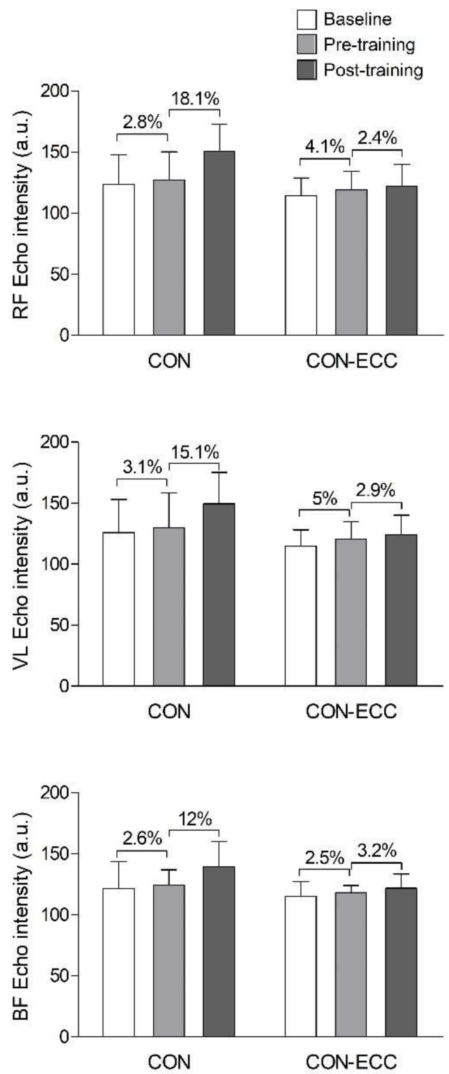

Figure 14. Results for echo intensity. RF: rectus femoris; VL: vastus lateralis; BF: biceps femoris; CON: concentric; CON-ECC: concentric-eccentric.

4.4 Final Considerations and Future Expectations

This randomized controlled trial is still ongoing at the time of this thesis presentation. We opted for presenting the data from 11 participants we had all data processed in order to show the directions of our next steps in this project. Our initial hypothesis was that the concentric-eccentric training would produce greater improvements on muscular and functional parameters.

Considering the functional parameters evaluated here, both groups improved the sit-to-stand performance from pre- to post-training. However, the concentric group presented better improvements. For the six-minute walking, stair ascent and stair descent tests, only the concentric group improved. On the other hand, only the concentric-eccentric training led to better improvements in the preferred gait speed and jump height. TUG and balance did not improve for both groups.

The concentric group showed more improvements for isometric torque, in three of the four tests, and the concentric-eccentric group in one test. However, both groups showed better results from baseline and pre-training assessments. Considering the concentric torque, both groups improved the performance, but the CON-ECC showed a greater change. For eccentric torque, the CON group had greater improvements.

When considering the power assessments, both groups showed greater values at post-training. However, the changes were greater for the CON-ECC group. Both trainings were effective to improve RTD parameters. However, the CON group showed greater improvements for knee flexion RTDs and the CON-ECC for the knee extension RTDs.

Structural parameters had only few changes. RF fascicle length improved only in the CON-ECC group, and VL in both groups. Pennation angle was greater only for RF in the CON group. In addition, muscle thickness improved more for VL and BF in the CON group and for RF in the CON-ECC group. Muscle echo intensity did not improve for none of the analyzed muscles.

From the results described above, it is possible to note that our initial hypothesis was not confirmed, once that for some outcomes, the CON group presented better improvements, and for others, the CON-ECC showed greater improvements. It is important to highlight that the results presented in this chapter consider only a few number of participants, and, therefore, the effects of the concentric and of the concentric-eccentric training programs remain inconclusive. In addition, the comparison between the different training groups should be looked with caution, due to the different number of subjects in each group and due to the different losses to follow-up between the groups.

It is expected that, after the end of this study, when all the subjects necessary, according to the sample size calculation, will be completed the training, it will be possible to answer whether the effects of a concentric or a concentric-eccentric resistance training for knee flexors and extensors are similar or whether they lead to different adaptations for older men.

CONSIDERAÇÕES FINAIS

A partir da presente tese, objetivamos identificar quais parâmetros estruturais e de função muscular de membros inferiores apresentam melhor relação e podem explicar o desempenho em tarefas funcionais, revisar sistematicamente a literatura quanto aos efeitos de treinos de força com diferentes tipos de contrações musculares para idosos, e determinar os efeitos de um treinamento de força concêntrico versus um treinamento concêntrico-excêntrico para a musculatura flexora e extensora do joelho sobre parâmetros de estrutura e função muscular e funcionalidade de homens idosos.

Com relação aos parâmetros que estão associados com e podem determinar a capacidade funcional dos idosos, verificamos, conforme demonstrado no Capítulo 1, que a estrutura (principalmente a eco intensidade e a espessura) dos músculos tibial anterior e vasto lateral foram os parâmetros melhor correlacionados com as tarefas de marcha no solo e marcha com transposição de obstáculo analisadas, bem como para o teste de sentar-e-levantar de cinco repetições. A eco intensidade revela o que chamamos de qualidade muscular, sendo que músculos com melhor qualidade são aqueles que apresentam menor quantidade de tecido adiposo e tecido conectivo intramuscular, tendo assim maior quantidade de tecido muscular propriamente dito. Essa variável, juntamente com a espessura muscular, a qual está relacionada com a quantidade de massa muscular, podem ser consideradas como parâmetros importantes para a funcionalidade em tarefas de marcha. A força isométrica apresentou, em geral, fraca correlação com os parâmetros analisados, o que não era esperado, uma vez que a espessura muscular apresentou boa correlação com a funcionalidade e tem relação direta com a capacidade de produção de força. Entretanto, a força isométrica não é determinada apenas pela estrutura muscular, mas também pela ativação muscular, de modo que isso talvez explique a baixa correlação da força isométrica com os parâmetros de funcionalidade. Além disso, talvez a força em contrações concêntricas e/ou excêntricas se correlacione melhor com as tarefas funcionais avaliadas nesse estudo, pois estão diretamente relacionadas com o tipo de contração utilizada para realizar essas tarefas funcionais.

Visando responder ao mesmo objetivo, no Capítulo 2, investigamos a associação entre parâmetros musculares de flexores e extensores de joelho com a funcionalidade, avaliada por um número maior de testes do que no capítulo anterior. Verificamos que os parâmetros musculares mais associados com a funcionalidade foram o comprimento de fascículo do músculo vasto lateral e o torque concêntrico de extensores de joelho. O fascículo muscular tem relação direta com a excursão muscular e com a velocidade de contração. Portanto, parece natural que indivíduos com fascículos mais longos apresentem melhor desempenho nos testes funcionais, pois conseguem talvez responder mais rapidamente aos estímulos dos testes de funcionalidade. Já a associação do torque concêntrico com a funcionalidade fornece evidências para a ideia que abordamos no parágrafo anterior, de que a força gerada em contrações dinâmicas tem maior relação com a funcionalidade em função de todos os testes funcionais envolverem contrações concêntricas. Portanto, programas de reabilitação de idosos devem utilizar exercícios de força em contrações concêntricas e excêntricas. Enquanto as contrações concêntricas dependem mais da capacidade de ativação na geração de força, as contrações excêntricas utilizam também os tecidos conectivos para gerar força enquanto o músculo se alonga ativamente. Esse alongamento ativo é um fator importante para a sarcomerogênese, levando o músculo a um aumento do comprimento do fascículo. Como idosos apresentam hipotrofia em paralelo (redução do número de miofibrilas por fibra muscular) e em série (redução do comprimento de fibras por perda de sarcômeros em série nas miofibrilas), assim como atrofia (perda de fibras musculares por morte neuronal), nos parece adequado que programas de treinamento de força utilizem tanto contrações concêntricas quanto excêntricas em seus exercícios.

Para verificar como o treinamento de força pode influenciar nos parâmetros investigados nos dois primeiros capítulos (estrutura e função muscular e funcionalidade), no Capítulo 3, realizamos uma revisão sistemática. A partir da mesma, foi possível constatar que existem poucos estudos controlados investigando os efeitos de treinos concêntricos e/ou excêntricos realizados em dinamômetro isocinético, para indivíduos idosos, principalmente investigando os efeitos sobre a estrutura muscular e sobre a funcionalidade. Verificamos que tanto o treino de força concêntrico quanto o excêntrico apresentam efeitos positivos sobre a função muscular e a funcionalidade de idosos. Entretanto, a lacuna em relação aos efeitos do treinamento de força puramente concêntrico comparado a um treinamento misto (concêntrico-excêntrico) sobre a estrutura muscular e sobre a funcionalidade não nos permite chegar a uma conclusão definitiva em relação a se um dos dois tipos de treinamento seria superior ao outro para melhorar a funcionalidade e a estrutura e função muscular.

A partir disso, buscamos preencher essa lacuna no Capítulo 4, onde dados preliminares de um ensaio clínico randomizado realizado para homens idosos foram apresentados. Nesse estudo, objetivamos verificar os efeitos de um treinamento de força concêntrico e de um treinamento concêntrico-excêntrico para a musculatura flexora e extensora do joelho sobre parâmetros musculares e funcionais. O protocolo de treino com duração de oito semanas, totalizando 16 sessões de treino, teve essa temporalidade definida tendo em vista já ter sido demonstrado que adaptações neurais e musculares ocorrem a partir de 4 semanas, e que oito semanas parece ser um período de tempo adequado para que as adaptações estruturais e funcionais possam ocorrer. Os dados preliminares demonstram que ambos os grupos de treino apresentaram melhoras tanto musculares quanto funcionais após o treinamento. Porém, devido ao baixo número de sujeitos, e disparidade entre os grupos, ainda não é possível afirmar qual dos dois treinamentos é mais efetivo ou se os dois apresentam os mesmos efeitos, o que esperamos determinar ao final do estudo. Ainda assim, os dados preliminares sugerem que as adaptações no músculo RF estão de acordo com o que se esperaria dos dois tipos de treinamento. Mais especificamente, o treinamento de força concêntrico parece levar a uma redução do comprimento dos fascículos desse músculo, com aumento do ângulo de penação de suas fibras. Já o treinamento concêntrico-excêntrico, parece levar os fascículos desse músculo a aumentarem o seu comprimento e a reduzirem o ângulo de penação, concordando com os efeitos do tipo de sobrecarga mecânica aplicada ao músculo por cada tipo de treinamento. Entretanto, como são dados iniciais e, portanto, qualitativos, não podemos ainda chegar a uma conclusão sobre os efeitos desses dois tipos de treinamento de força sobre a estrutura e função muscular e sobre a funcionalidade em idosos.

A partir dos resultados da presente tese, é possível concluir que os estudos realizados na mesma trouxeram importantes resultados para a linha de investigação dos fatores envolvidos com o envelhecimento e com a manutenção da capacidade funcional de idosos. Além disso, os resultados apresentam aplicações práticas para o desenho de estudos futuros com a população idosa, bem como para a prática clínica.

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APÊNDICES

APÊNDICE A: Correlation coefficients between functional parameters and peak torque, concentric power and rate of torque development. Significant correlations are highlighted.

	6MWT	30STS	TUG	Jump height	Balance	Gait speed	Stair ascent	Stair descent
Isometric Torque								
Isom Ext 60º	0.40	0.54	-0.70*	0.45	0.15	0.48	-0.14	-0.28
Isom Ext 90º	0.76**	0.72**	-0.65*	0.58*	0.23	0.26	-0.49	-0.37
Isom Flex 30º	0.41	0.38	-0.38	0.18	0.16	0.14	-0.16	-0.15
Isom Flex 90º	0.29	0.39	-0.44	0.05	0.27	0.02	-0.06	-0.41
Concentric Torque								
Con Ext 60º.s-1	0.25	0.66*	-0.42	0.58*	-0.14	0.42	-0.57*	-0.20
Con Ext 180º.s-1	0.51	0.72**	-0.34	0.54	-0.14	0.53	-0.23	-0.07
Con Flex 60º.s-1	0.40	0.67*	-0.54	0.37	0.06	0.44	-0.33	-0.06
Con Flex 180º.s-1	0.35	0.74*	-0.43	0.45	0.27	0.17	-0.50	-0.02
Eccentric Torque								
Ecc Ext 60º.s-1	0.56*	0.55*	-0.45	0.43	0.18	0.50	0.004	-0.14
Ecc Ext 120º.s-1	0.48	0.31	-0.20	0.32	0.10	0.47	0.10	0.07
Ecc Flex 60º.s-1	0.51	0.39	-0.53	0.14	0.21	0.15	-0.03	-0.25
Ecc Flex 120º.s-1	0.52	0.27	-0.31	0.22	0.27	0.40	0.19	0.09
Power								
Ext Pow 60º.s-1	0.52	0.70**	-0.26	0.60*	-0.08	0.45	-0.41	-0.05
Ext Pow 180º.s-1	0.15	0.55*	-0.08	0.33	-0.21	0.51	-0.28	0.06
Flex Pow 60º.s-1	0.11	0.62*	-0.20	0.33	0.07	0.30	-0.43	0.12
Flex Pow 180º.s-1	-0.24	0.36	0.22	0.11	-0.21	0.31	-0.40	0.11
Rate of torque development								
Isom Ext 60º RTD 50	0.47	0.49	-0.18	0.37	-0.31	0.44	-0.04	-0.23
Isom Ext 60º RTD 200	-0.08	0.24	-0.06	0.23	-0.28	0.55	-0.06	-0.03
Isom Ext 90º RTD 50	0.47	0.59*	-0.06	0.45	0.13	0.24	-0.35	-0.24
Isom Ext 90º RTD 200	-0.06	0.37	0.01	0.39	-0.08	0.49	-0.31	-0.01
Isom Flex 30º RTD 50	0.49	0.35	-0.01	0.12	-0.08	0.53	-0.02	-0.23
Isom Flex 30º RTD 200	0.28	0.33	0.04	0.008	-0.05	0.58*	-0.02	-0.02
Isom Flex 90º RTD 50	-0.13	0.17	0.06	0.24	0.12	0.28	-0.13	-0.03
Isom Flex 90º RTD 200	0.54	0.47	-0.11	0.28	0.07	0.29	-0.25	-0.30

Isom: isometric; Con: concentric; Ecc: eccentric; Ext: extension; Flex: flexion; 6MWT: six-minute walk test; 30STS: 30-seconds sit-to-stand.
*Significant correlation at $p<0.05$. **Significant correlation at $p<0.01$.

APÊNDICE B. Complete description of the search strategy used in Medline via Pubmed database

((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) AND (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) AND (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) AND (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))