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Effectiveness of Eccentric-Focused Training on Muscle Strength in Older Adults

A literature review

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The purpose of this review is to gather evidence of the effectiveness of eccentric-focused training in increasing muscle strength in older adults. Resistance training is known to improve the muscle strength of older adults. Everyday activities, such as walking, requires sufficient strength in concentric, isometric and eccentric contractions. Eccentric contractions consume less energy than isometric or concentric contractions. Force production in eccentric movements is also well preserved in older adults compared to the isometric and concentric contractions. It is hypothesized that utilizing this well preserved eccentric strength in training leads to increased muscle strength.

Studies focusing on eccentric training of older adults were searched from PubMed and PEDro in a systematic manner using defined keywords and inclusion criteria. A research matrix with relevant results was composed of the final selection of studies. The main findings of these studies were analysed and discussed.

The results of this review support the conclusion that eccentric-focused training is effective in increasing isometric or eccentric strength in older adults. The studies comparing concentric and eccentric training also suggest that increases in muscle strength are training specific. Eccentric training was superior in increasing eccentric strength, and vice versa for concentric training.

The practical benefit of eccentric training seems most suited for frail older adults, who have diminished muscle strength due to sarcopenia or other causes. However, there is large variability in muscle strength progress between individuals after eccentric training interventions. Based on the reviewed studies, eccentric-focused training presents as a safe and effective training method among older adults.

Keywords	eccentric, resistance training, muscle strength, older adults

Contents

1 Introduction

Muscle strength is valuable for all humans. Older adults have diminished muscle strength due to sarcopenia and the effects of physiological aging (Faulkner – Larkin – Claflin – Brooks 2007.) Physical activity and resistance training can reduce the decline of strength during aging (Hunter – McCarthy – Bamman 2004.) Eccentric movements in particular are beneficial in improving strength (Symons, Vandervoort, Rice, Overend, Marsh 2005), preventing muscle strains (Hibbert – Cheong – Grant – Beers – Moizumi 2008) and rehabilitating tendinopathies (Sussmilch-Leitch – Collins – Bialocerkowski – Warden – Crossley 2012). The focus of this review is on eccentric-focused training methods and their effects on the muscular strength in older adults. This review aims to examine if eccentric training is effective in counteracting the effects of sarcopenia and age-related decline in strength. Additionally the practical implications of when eccentric training should be used instead of traditional training is discussed.

The increasing number of the aging demographics presents challenges in the management of public health. At the end of 2013, there were 1 056 547 people aged 65 years or older in Finland, twice as many as compared to 1975 (Statistics Finland 2014). Physical activity and exercise are key habits in increasing and maintaining quality of life, mobility and health. The increasing scientific knowledge of the individual components of different training regimes may help design more sophisticated and effective exercise solutions for the aging population.

Skeletal muscle is a remarkable tissue capable of producing enough force to lift heavy objects, while having precision to perform subtle and coordinated eye movements to track an object moving through space. Skeletal muscle is also one of the most durable tissues during aging, and responds well to physical exercise even at an old age. The ability to produce strength in the lengthening part of a muscle contraction is a key element in movement quality, and it is well maintained in older adults. In recent years the method of training the eccentric part of movements has gathered increasing scientific interest and promising results, thus sparking interest in conducting a literature review by the author.

2 Purpose and goals of the thesis

The purpose of this thesis is to gather evidence of the effectiveness of eccentric-focused training in increasing muscle strength in older adults. Several reviews of resistance training for older adults have been carried out in recent years, but only few have addressed the effects between the different types of muscle contractions in relation to exercise performance. To achieve the designated purpose, goals for this thesis are threefold. First, the effects of aging for musculoskeletal function are described to establish background knowledge on the subject in question. Second, studies focusing on eccentric training for older adults are gathered for analysis in order to understand the relationship of different training interventions and muscle strength. Third, the results of the review and practical applications of eccentric-focused training are discussed.

The methods used in this literature review were designed with the help of The Matrix Method by Garrard (2014). The first step of this review was the immersion of general knowledge about geriatrics, exercise physiology and eccentric-type training. This immersion was conducted in a non-systematic manner using books, online databases and peer conversation. The second step was defining the inclusion criteria and conducting an online database search in a systematic manner. The third step was collecting a pool of studies for a review, and composing a research matrix of the relevant results. This matrix presents information of the author, title, study design, number of subjects, intervention and relevant results. In the fourth step the results were laid out in thematic manner, and the findings were discussed in the final chapter.

3 Background on aging and eccentric-focused training

The appeal of eccentric-focused training regimes stems from the low-cost and high-force abilities of the eccentric muscle action. This chapter describes key elements in muscle function, effects of aging in musculoskeletal performance and the effects of eccentric-focused training for older adults. For clarification, the term ‘muscle’ used throughout this thesis relates to skeletal muscle. ‘Muscle strength’ and ‘strength’ are used to describe the ability of a muscle group to develop maximal contractile force against a resistance in a single contraction. ‘Muscle torque’ is used specifically when referring to a muscle group producing contractile force to rotate an object about an axis, fulcrum or pivot, e.g. a knee extension producing a certain number of newton meters as a measurement of muscle torque.

3.1 Muscle contraction types and energetics

A traditional approach to the musculoskeletal system is through biomechanical levers and pulling forces. However, the ability of a muscle to pull while shortening, lengthening and without a change of length creates grounds for a more comprehensive understanding of the human movement apparatus. Concentric, eccentric, and isometric contractions are most frequently used to describe a contracting muscle while shortening, lengthening and staying at the same length, respectively. Miometric and pliometric contractions have also been proposed due to their appealing Greek prefixes ‘mio’ (shorter) and ‘plio’ (longer), but they have never gained wide popularity. Terminologically lengthening and shortening contractions provide the greatest clarity to describe the direction of the contraction, but ‘concentric’ and ‘eccentric’ remain to be used in literature. (Faulkner 2003.)

The direction of the contraction depends on the force generated by the contraction, and the external load working against the tension. A load greater than the force produced by the contraction results in a lengthening muscle, and vice versa. A fully active lengthening muscle produces more tension than a fully active isometrically contracting muscle. In contrast, a maximally active shortening muscle produces the least amount of tension compared to the maximal eccentric and isometric contractions. (Abbott – Aubert 1952.)

In addition to eccentric contractions being able to produce the highest levels of tension, it is also the least energy-consuming contraction type. The energetic cost of force production is highest in concentric and lowest in eccentric contractions. In a classical study by Wallace Fenn in 1923, a stimulated muscle that was allowed to shorten liberated an increased amount of heat in proportion to the distance shortened and tension created (Rall 1982). This phenomenon became known as the 'Fenn effect'. In the same experiments, a stimulated muscle that was stretched was found to liberate less heat than an isometric contraction of the same duration and magnitude. These observations have later been confirmed by more sophisticated tools than what were available nearly a century ago (Ortega *et al* 2015). Using a magnetic resonance spectroscopy and an *in vivo* force clamp, Ortega *et al* found that the energy cost of force production for concentric contractions was nearly 50% greater than the cost of isometric contractions. Compared to isometric contractions, the energy cost of force production was reduced by over 10% in eccentric contractions.

The mechanisms behind the low energetic cost and high force producing abilities of eccentric contractions have been a topic of interest among muscle physiologists for decades. In the classical sliding filament model of the muscle contraction, which was composed concurrently in 1954 by two independent research teams, the actin and myosin filaments use adenosine triphosphate (ATP) as a power source to slide past each other and create movement (Szent-Györgyi 2004). However, the sliding filament model has failed to explain the peculiar features of eccentric contractions. In an attempt to refine the sliding filament model, many physiologists have aimed their focus towards the behaviour of elastic components of the muscle in different contraction types.

Titin is one of the most studied elastic component of the muscle, and it has been shown to tremendously affect the force producing capabilities of muscle tissue (Herzog 2014). Also called 'active molecular spring', titin resides in the sarcomeres of muscle tissue alongside the myosin and actin filaments, and operates differently in concentric and eccentric contractions. The influx of calcium in muscle contractions has been shown to increase titin stiffness in eccentric contractions by binding certain parts of the titin molecule to the actin filament (Powers *et al* 2014). Additionally, titin has been shown to provide over 90% of the passive force of single myofibrils (Linke 2000), and its contribution to the passive force is directly related to the length of the muscle sarcomere (Herzog J – Leonard – Jinha – Herzog W 2012).

Muscle strength in older adults during eccentric contractions is well maintained compared to concentric or isometric contractions (Vandervoort – Kramer – Wharram 1990; Horstmann *et al* 1999; Pousson – Lepers – Hoecke 2001). Roig *et al* (2010) reviewed evidence of the preservation of eccentric and concentric strength between young and older adults. The difference in eccentric strength between old and young adults was found to be significantly smaller than the difference in concentric strength. However, it is noteworthy that individual variations in strength level differences spanned from 2% to 48% among old adults. The phenomenon of eccentric strength preservation was found in both older men and women, albeit to a larger degree in women.

Possible mechanisms for the preservation of eccentric strength during aging have been sought from neurological, mechanical and cellular alterations (Roig *et al* 2010). Decreased agonist activation and increased antagonist activation in shortening contractions due to decreased neurological activation might explain deficits in concentric strength, making eccentric strength appear stronger in comparison. Increased passive stiffness of the muscle and adjacent connective tissue has also been proposed as a contributing factor. As mentioned previously, lengthening contractions activate the elastic components of the muscle sarcomere in force production, and this feature may work in the favour of older adults.

In addition to the well preserved eccentric strength, older adults also show increased amount of residual force enhancement (RFE) when compared to younger adults (Power – Rice – Vandervoort 2012; Power – Makrakos – Rice – Vandervoort 2013). RFE is defined by an increase in isometric tension after a lengthening contraction, compared to a purely isometric contraction at the same muscle length. Higher relative eccentric strength and RFE have been shown in ankle dorsiflexors and knee extensors of older adults. The studies by Power *et al* (2012) present a 250% increase in the maximal isometric torque following an eccentric contraction, compared to a maximal isometric contraction without a preceding contraction. In other words, RFE can be utilized for a stronger isometric and concentric movement, if the muscle is first allowed to actively resist the lengthening. The utilization of titin in eccentric contractions and the following isometric or concentric movement as a molecular spring may explain the relatively larger enhancement of force in older adults compared to the young (Rassier 2012.)

3.2 Sarcopenia – the loss of muscle strength and mass

Aging is associated with atrophy of the musculoskeletal system and decreased muscle strength, with various studies reporting a 30-50% decrease in muscle mass between the ages of 40 and 80. This loss consists of a decrease in the total number of muscle fibres, and of the shrinking size of muscle fibres. Along with the decrease of muscle mass, muscle strength is diminished. This phenomenon is detectable in both sedentary types and athletes, but physical exercise seems to be an effective way of slowing down the inevitable decline. (Faulkner – Larkin – Claflin – Brooks 2007.)

The loss of muscle mass has been proposed as a plausible cause for the decrease of muscle strength. In a study examining the changes in muscle strength and mass of 1880 older adults during three years, the decrease of muscle strength was found to be significantly greater than the loss of muscle mass, suggesting that the loss of muscle mass by itself is not a sufficient explanation for the decline in strength (Goodpaster *et al* 2006). Authors proposed muscle quality as a possible factor to account for strength loss. Furthermore, increases in muscle mass were not found to be directly correlated with increases in muscle strength.

Body composition and lean body mass are affected by age and sex. Grossly 25-40% of total body weight is skeletal muscle in humans over 60 years old. The relative difference between total skeletal muscle mass between men and women is more pronounced in upper body musculature. Men have a bigger percentage of their muscle mass in the upper body region. (Janssen – Heymsfield – Wang – Ross 2000.)

Another significant factor in sarcopenia is the loss of spinal motor neurons (Kim – Choi 2013). Muscle fibres are innervated in bundles by efferent motor neurons, also called motor units. Adequate motor unit recruitment is an essential aspect of being able to perform daily musculoskeletal functions, and a decreased number of motor units leads to loss of muscle strength. The age-related loss of motor neurons seems to be independent of physical exercise, but strength training has been shown to benefit other neuromuscular attributes of muscle function, such as the rate of force development. The loss of motor neurons is linked to hormonal changes, cell signalling alterations and cell oxidative stress. (Aagaard – Suetta – Caserotti – Magnusson – Kjaer 2010.)

3.3 Sarcopenic obesity

Excessive weight gain has adverse effects on the health and quality of life in older adults. Obesity is related to cardiovascular diseases and metabolic syndromes, and it has also been independently associated to all-cause mortality (Zamboni *et al* 2005). While the body mass index (BMI) is traditionally used to classify weight from normal to obese, it gives no indication of the amount of lean body mass (Prentice – Jebb 2001). Increases in body fat, specifically visceral fat, is a common phenomenon occurring in all aging humans (Hunter – Gower – Kane 2010). Lean body mass and fat distribution may be better determinants of the health risks associated with obesity. Furthermore, studies suggest that the prevalence of obesity is increasing at old ages (Zamboni *et al* 2005).

Sarcopenic obesity is used to describe older obese humans with an age-related decline in muscle strength and mass. In contrast to healthy older adults, the gain of weight is not distributed evenly as fat and lean body mass. As a result, the body fat percentage becomes relatively high, while muscle and bone mass become relatively low. These outcomes have significant effects on physical functioning and the ability to maintain muscle strength. (Stenholm *et al* 2008)

Although obesity is a multifactorial syndrome, skeletal muscle metabolism plays a big part in the resting and active energy expenditure (Zurlo – Larson – Bogardus – Ravussin 1990). Lemmer *et al* (2001) found a significant increase in the resting metabolic rate of young and old men, but not women, after 24 weeks of resistance training. Higher resting metabolic rates have also been recorded after a single bout of resistance training. Melby *et al* (1985) found increases of 4.7% to 9.4% in the resting metabolic rate of adult participants 15 hours after a training session.

3.4 Definition and effects of eccentric resistance training

Resistance training, or strength training, by definition means different ways of applying resistance against a force produced by a muscle, typically in levels that exceed the anaerobic threshold. Resistance can be applied with using one's own bodyweight, external weights such as a barbell, or exercise machines, among other things. Movement velocities and repetition ranges may vary, but a common goal is to increase muscle strength and mass to a specified body part. (Faigenbaum – Myer 2010.)

The effects of resistance training by older adults have been studied extensively in the recent years (Borde – Hortobagyi – Granacher 2015; Latham – Chiung-ju 2010; Mayer *et al* 2011). Most guidelines for physical health recommends individuals to perform some kind of resistance training in addition to aerobic training. Finnish guidelines recommend this type of training for all adults at least twice per week, in addition to some kind of mobility and balance training (Tarnanen *et al* 2010). In a similar fashion, the guidelines for physical activity in the United States of America recommend moderate to high intensity strength training at least twice a week for all major muscle groups (ODPHP 2016).

Eccentric resistance training refers to a method of training where the emphasis is placed on the eccentric or lengthening phase of the movement (Lorenz – Reiman 2011). This type of training has gained popularity largely because of the energy-efficiency of eccentric contractions. Huggett *et al* (2004) compared the heart rate and blood pressure responses to isometric and eccentric resistance training protocols. They found that eccentric exercise allowed the participants to train at the same torque output with less cardiovascular stress than during isometric exercise. Consistent with the previous findings comparing isometric and eccentric muscle action, they also found maximal eccentric torque higher than maximal isometric torque. Whether these higher levels of tension translate to increases in muscle strength in the long term is not clear. The theoretical basis for the force-enhancing abilities of eccentric contractions is yet to be elucidated, but the engagement of titin and other passive structures in the muscle sarcomere has been proposed as a plausible explanation. (LaStayo *et al* 2014.)

Traditional aerobic exercise tools, such as ergometers, may be modified to induce eccentric contractions. While these types of exercise protocols are not resistance training *per se*, they can be modified to operate on higher levels of torque than in normal aerobic exercise. Resisting the counter-clockwise motion of bicycle pedals can be significantly more strenuous to the muscles than pedalling forward in a concentric-focused manner. LaStayo *et al* (2003) compared the effects of eccentric ergometer training with traditional resistance training on frail older adults. The ergometer intervention produced significant improvements in strength and functional abilities of the participants. Gault *et al* (2012) compared the effects of downhill and normal level treadmill walking on the functional mobility and strength of older adults. Improvements on functional mobility were found in both groups, but no changes in quadriceps strength were found in either group. Although downhill treadmill walking included significantly more eccentric muscle work, it did not show enhanced results compared to the normal level treadmill group. Although eccentric training is energy-efficient, it seems that a sufficient level of intensity is required in the eccentric phase of the movement to gain noticeable results in muscle strength.

Eccentric-focused training does not come without disadvantages. All novice and elite athletes are familiar with soreness experienced the day after intensive exercise, particularly after a break in training. Delayed onset muscle soreness (DOMS) is characterised by sensations of pain and stiffness in muscle tissue and musculotendinous areas after unaccustomed exercise. It can also negatively affect physical performance. The sensations range from mild to severe, and normally peaks 24-48 hours after exercise. Symptoms may persist up to 7 days, depending on the intensity of the exercise and conditioning of the exercised muscles. DOMS is related to microtrauma in the muscle tissue and disruption of sarcomeric structures, and eccentric contractions in particular cause this type of damage. Adjusting the intensity of the exercise and pre-conditioning the targeted muscles affect the level of experienced DOMS. (Cheung – Hume – Maxwell 2003.)

Numerous treatments including massage, ultrasound and conventional stretching have been suggested for the treatment of DOMS (Connolly – Sayers – McHugh 2003). Although there is little evidence of effective treatments for DOMS, there is an effective preventive method: the *repeated bout effect* (McHugh – Connolly – Eston – Gleim 1999). In a study carried out with older adults, a single bout of low-intensity eccentric exercise was shown to effectively alleviate DOMS caused by high-intensity eccentric exercise when the bouts were separated by seven days (Chen *et al* 2013). The repeated bout effect supports the idea of progressive increases in intensity to prevent severe DOMS and subsequent decreases in performance.

4 Method: literature review

The studies reviewed in this thesis were searched in a systematic manner with pre-defined keywords and inclusion criteria. The goal of this approach was to achieve sufficient comparability between the selected studies, which allows for a better understanding of the effects of eccentric training on values of muscle strength.

4.1 Database search and inclusion criteria

PubMed and Physiotherapy Evidence Database (PEDro) were searched with customized search functions. PubMed was searched using the following keywords: "(resistance training OR strength training OR training) AND (older adults OR elderly) AND (eccentric)". PEDro was searched with the keyword "eccentric" in the subcategory "gerontology".

Table 1. Criteria used in the inclusion of studies for the review.

	Inclusion criteria
1.	RCT, cohort or pilot study
2.	subjects mean age over 60
3.	some form of eccentric resistance exercise as an intervention
4.	standardized strength assessment before and after intervention

Inclusion criteria are listed in table 1. The results of the database search were screened with these prerequisites, and studies which did not fulfill the criteria were excluded in the study selection process. Reference lists of review studies found in the search were screened for additional studies, and studies matching the criteria were included. As a final step of the study selection process, duplicate studies were removed from the final pool of selected studies.

4.2 Study selection

Database search of PubMed and PEDro returned a combined 391 results. The study selection process is illustrated in figure 1.

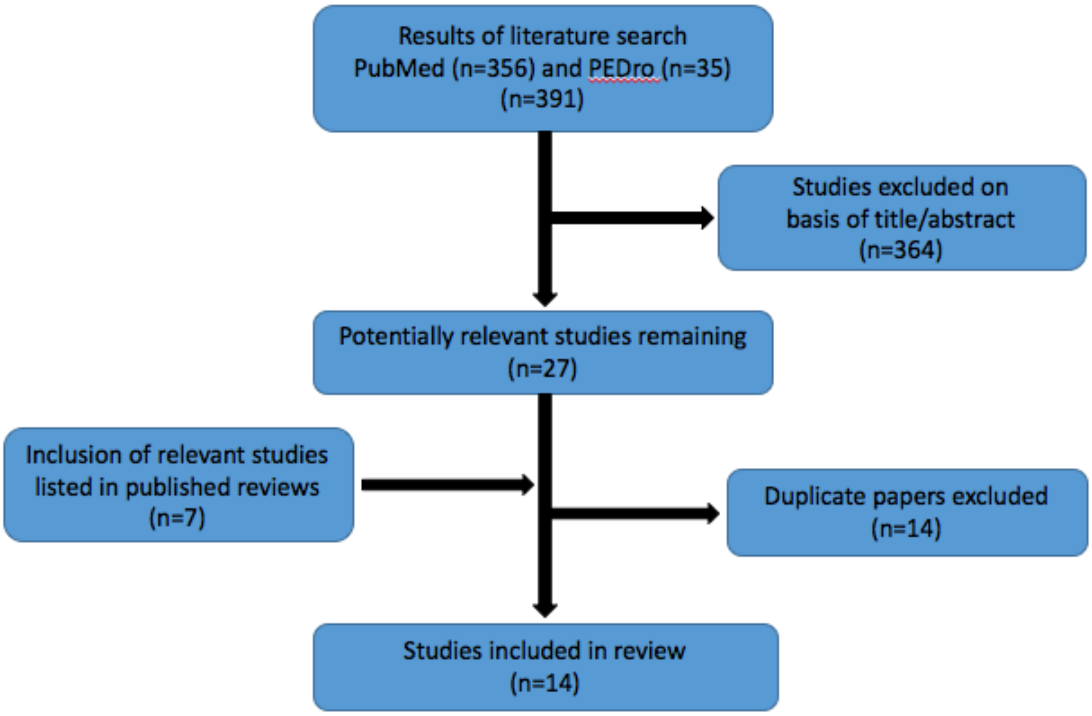

Figure 1. Illustration of the database search and the study selection process

After screening the titles and abstracts, 27 studies were selected as potential candidates for the review. Reference lists of the reviews found in the search were screened for further inclusion of studies, and seven studies were added to the pool. After removing duplicates from this final pool of studies, 14 studies remained and were selected for the review.

5 Eccentric training for eccentric results

This chapter serves as a summary of the results of the selected studies. Each study was reviewed by the author, after which the relevant results were assembled in a table and summarized in a thematic manner. For clarification, the word ‘strength’ is used as an umbrella term for the ability to produce contractile force, while ‘torque’ and ‘repetition maximum’ are specific measures of strength in a certain measurement protocol. ‘Torque’ in this chapter refers to muscle torque, which is created by contractile force of muscles creating a rotational force about an axis. ‘Repetition maximum’ refers to an ability to successfully complete a maximum number of repetitions in a given movement or exercise. (Contreras 2013)

5.1 Study table and statistics

A study table (table 2) was conducted based on the final selection of studies.

Table 2. Table of the selected studies and relevant results.

CON = Concentric
ECC = Eccentric
ISO = Isometric
RM = repetition maximum
Conv = Conventional
Ext = extension
RCT = Randomized controlled trial
Trad = Traditional

Author	Title / Design	Subjects	Groups / Intervention	Results
1. LaStayo, Ewy, Pierotti, Johns, Lindstedt (2003)	The Positive Effects of Negative Work: Increased Muscle Strength and Decreased Fall Risk in a Frail Elderly Population (Cohort)	n=**21** 80y ECC (n=**11**) TRAD (n=**10**)	ECC: eccentric ergometer TRAD: traditional weight training 11 weeks total, 3x/week	Knee ext isometric peak torque: ECC: +60% TRAD: +15% Muscle fiber CSA: ECC: +60% TRAD: +41%
2. LaStayo, Marcus, Dibble, Smith, Beck (2011)	Eccentric exercise versus Usual-care with older cancer survivors: The impact on muscle and mobility- an exploratory pilot study (RCT Pilot study)	n=**40** 74±6y RENEW (n=**20**) UCG (n=**20**)	RENEW: recumbent eccentric stepper UCG: no exercise intervention 12 weeks total, 3x/wk, 3-20min	Knee ext isometric peak torque: RENEW: +11% UCG: +1% Stair climbing leg power: RENEW: +29% UCG: +8% Quadriceps muscle size: RENEW: +4% UCG: +<1%

Author	Title / Design	Subjects	Groups / Intervention	Results
3. **Theodorou, Panayiotou, Paschalis, Nikolaidis, Kyparos, Mademli, Grivas, Vrabas (2013)**	Stair descending exercise increases muscle strength in elderly males with chronic heart failure (Cohort)	n=**12** 60-70y SAG (n=**6**) SDG (n=**6**)	SAG: Stair ascending group SDG: Stair descending group 6 weeks total, 3x/wk, 4x3min	Knee ext isometric peak torque: SAG: +5.9% SDG: +8.8% Knee ext eccentric peak torque: SAG: +7.1% SDG: +12.3% Knee ext concentric peak torque: SAG: +9.6% SDG: +7.7%
4. **Symons, Vandervoort, Rice, Overend, Marsh (2005)**	Effects of maximal isometric and isokinetic resistance training on strength and functional mobility in older adults. (RCT)	n=**30** 73±7y CON-TG (n=**10**) ISO-TG (n=**11**) ECC-TG (n=**9**)	Dynamometer exercise , con/iso/ecc 12 weeks total, 3x/wk	Knee ext isometric peak torque: CON-TG: +17.3% ISO-TG: +27.7% ECC-TG: +25.5% Knee ext concentric peak torque: CON-TG: +22.1% ISO-TG: +15.1% ECC-TG: +10.0% Knee ext eccentric peak torque: CON-TG: +17.9% ISO-TG: +16.5% ECC-TG: +26.0%
5. **Hortobagyi, DeVita (2000)**	Favourable neuro-muscular and cardiovascular responses to 7 days of exercise with an eccentric overload in elderly women. (RCT)	n=**30** 71.4±4.8 Eccentric (n=**10**) standard (n=**10**) non-exercise (n=**10**)	Cybex knee extension dynamometer, ecc/standard. 7 consecutive days of exercise training.	Knee ext ecc, iso and con torque: Eccentric group: +19%, +16%, +16% Standard group: +9%, +5%, +7% Knee ext concentric 3RM: Eccentric group: +43% Standard group: +43% Knee ext eccentric 3RM: Eccentric group: +33% Standard group: +18%
6. **Reeves, Maganaris, Longo, Narici (2009)**	Differential adapta-tions to eccentric versus conventional resistance training in older humans (RCT)	n=**9** CONV (5F, 4M, 74±3y) n=**10** ECC (5F, 5M, 67±2y)	CONV: conventional resistance training. ECC: eccentric only re-sistance training. 14 weeks total, 3x/wk	Knee ext isometric peak torque: CONV: +8% ECC: +8% Knee ext eccentric peak torque: CONV: no changes ECC: +9-17% Knee ext concentric peak torque: CONV: +22-37% ECC: no changes Muscle thickness: CONV: +12% ECC: +12%

Author	Title / Design	Subjects	Groups / Intervention	Results
7. **Vaczi,** **Nagy,** **Köszegi,** **Ambrus,** **Bogner,** **Perlaki,** **Orsi,** **Toth,** **Hortobagyi** **(2014)**	Mechanical, hor-monal, and hyper-trophic adaptations to 10 weeks of eccentric and stretch-shortening cycle exercise training in old males (RCT)	SSC (n=**8**, 64.4±4.1y) ECC (n=**8**, 65.7±5.3y)	SSC: stretch-shortening contractions ECC: isokinetic eccentric contractions 10 weeks total, 2-3x/week	Knee ext isometric peak torque: +6% (SSC & ECC) Knee ext eccentric peak torque: +23% (SSC & ECC) Quad size: +2,5% (SSC & ECC) Rate of torque development: +30% (only SSC)
8. **Porter,** **Vandervoort** **(1997)**	Standing strength training of the ankle plantar and dorsiflexors in older women, using concentric and eccentric contrac-tions. (Cohort)	n=**15** 68±5y	all subjects did 3x8 CON ankle PF and ECC DF at +80% intensity 8 weeks total, 2x/week	CON DF peak torque: +30% ECC DF peak torque: +17% PF strength: no changes
9. **Melo,** **Quiterio,** **Takahashi,** **Silva,** **Martins,** **Catai** **(2008)**	High eccentric strength training reduces heart rate variabil-ity in healthy older men (Cohort)	n=**9** 62±2y	Isokinetic ecc strength training 2-4x8-12 at 75-80% intensi-ty 12 weeks total, 2x/week	Knee ext eccentric peak torque: +20% Knee flex eccentric peak torque: +13%
10. **Dias,** **Toscan,** **Camargo,** **Pereira,** **Griebler,** **Baroni,** **Tiggemann** **(2015)**	Effects of eccentric-focused and conventional resistance training on strength and functional capacity of older adults (RCT)	n=**26** 67±6y CTG (n=**13**) ETG (n=**13**)	CTG: 1.5s con, 1.5s ecc ETG: 1.5s con, 4s ecc 12 weeks total, 2x/week	Leg press 1RM: ETG: +13.35±12.42% CTG: +12.19±22.97% Knee extension 1RM: ETG: +24.17±9.67% CTG: +25.96±22.05%
11. **Raj,** **Bird,** **Westfold,** **Shield** **(2012)**	Effects of Eccentri-cally Biased versus Conventional Weight Training in Older Adults (RCT)	n=**28** 68±5y CONV (n=**12**) EB (n=**13**)	EB: 3x10 con at 50% inten-sity, ecc unilaterally CONV: 2x10 at 75% intensi-ty 16 weeks total, 2x/week	Knee ext isometric peak torque: CONV: +4% EB: +7% Knee ext concentric peak torque 120°/s: CONV: +8% EB: +7% Vastus lateralis thickness: EB +5%.
12. **Mueller,** **Breil,** **Vogt,** **Steiner,** **Lippuner,** **Popp,** **Klossner,** **Hoppeler,** **Däpp** **(2009)**	Different response to eccentric and concentric training in older men and women (RCT)	n=**62** 80.6±3.5y CT (n=**16**) RET (n=**23**) EET (n=**23**)	CT: cognitive training (no exercise) RET: leg press, knee ext, leg curl, hip ext EET: ecc ergometer training 12 weeks total, 2x/week	Knee ext isometric peak torque: EET: +7.5±1.7% RET: +2.3±2.0% Thigh muscle mass: EET: +2.5±0.6% RET: +2.0±0.3%

Author	Title / Design	Subjects	Groups / Intervention	Results
13. Leszczak, Olson, Stafford, Brezzo (2013)	Early adaptations to eccentric and high-velocity training on strength and functional performance in community-dwelling older adults. (RCT)	n=**19** 74.9±8.5y ECC (n=**10**) HVG (n=**9**)	Leg press, knee ext&curl ECC: 3x8-12 at 75%, ecc 3-5s HVG 3x8-12 at 50% con AFAP 8 weeks total, 2x/week	Knee ext 1RM: ECC: +49.5% HVG: +37.4% Knee flex 1RM: ECC: +36.6% HVG: +27.7% Leg press 1RM: ECC: +42.4% HVG: +45.2%
14. Dos Santos, Asano, Filho, Lopes, Panelli, Nascimento, Collier, Prestes (2014)	Acute and chronic cardiovascular response to 16 weeks of combined eccentric or traditional resistance and aerobic training in elderly hypertensive women: a randomized controlled trial. (RCT)	n=**60** 60-65y C (n=**20**) ERT (n=**20**) TRT (n=**20**)	16 weeks total, 3x/week TRT: 70-90% intensity, con&ecc ERT: 100-120% intensity, ecc only	Bench press 1RM: ERT: +54% TRT: +35% Leg press 1RM: ERT: +52% TRT: +33%

Nine of the 14 studies were randomized controlled trials, four were cohort studies and one was a pilot study. The total number of subjects was 377. Ten of the studies were conducted with healthy older adults, consisting of 244 healthy subjects. Three studies were conducted with cardiovascular patients, and one study was conducted with cancer survivors. Six of the studies included a purely eccentric exercise intervention, and eight had an intervention with both concentric and eccentric movement. Four studies had a control group with no exercise intervention. Twelve studies had two or more groups comparing eccentric-focused training to another type of intervention. Ten studies had interventions that continued for at least 10 weeks. All 14 studies had a training frequency of at least twice a week.

A dynamometer measuring muscle torque was the most used strength assessment device (11 studies). All 14 studies measured lower limb strength through either muscle torque or repetition maximum, and one study also measured upper body strength through bench press one repetition maximum (1RM). Knee extension torque was measured in 10 studies. Three studies measured the 1RM or the total amount of weight lifted.

5.2 Summary of results

The numbers inside the parenthesis in this section refer to the reviewed studies, which are accordingly numbered in the research matrix. First, studies that compared the effect of concentric, isometric and eccentric knee extension on muscle torque of the knee extension are analyzed. The results of the studies measuring repetition maximums were grouped into another subcategory. Finally, studies that found eccentric training less effective than another type of intervention were also grouped for analysis.

Eccentric knee extensions and eccentric lower limb resistance training improve peak eccentric and isometric torque. Nine out of 14 studies (1, 2, 3, 4, 5, 6, 7, 11 and 12) measured the effects of eccentric resistance training or eccentric knee extensions on peak isometric knee extension torque. All of these nine studies found increases in isometric torque of the knee extensors, although the range of improved torque levels was 6-60%. Six studies (3, 4, 5, 6, 7 and 9) measured the effects of eccentric resistance training or eccentric knee extensions on eccentric torque of the knee extensors, and all found significant improvements after the intervention with a variability of 9-26%.

Eccentric resistance training increases the RM. Four studies (5, 10, 13 and 14) measured the effects of eccentric knee extensions and eccentric focused resistance training on either 1RM or 3RM of a specific movement. The measured movements were knee extension (5, 10 and 13), knee flexion (13), leg press (10, 13 and 14) and bench press (14). All four studies found significant increases in the weight lifted in all measured 1RM or 3RM tests.

Concentric training is superior for concentric strength. Eccentric training was not the most effective form of intervention on concentric torque. Four studies (3-6) compared the effects of a concentric versus an eccentric knee extension protocol on concentric and eccentric knee extension torque. Three studies (3,4 and 6) found concentric knee extensions superior in increasing maximal concentric torque of the knee extension, and vice versa for eccentric knee extensions. Notably three of the four studies (3-5) found eccentric knee extensions superior in increasing maximal isometric knee extension torque.

6 Discussion: eccentric or traditional training?

The analysis in this chapter attempts to answer the questions composed in the beginning of this thesis: is eccentric training effective in increasing muscle strength in older adults? Also, what is the practical value of eccentric training for older adults? Additionally, the value of eccentric training as a tool in the physiotherapist's clinical setting is discussed.

The results support the following conclusions. First, eccentric-focused training is an effective way to increase eccentric and isometric strength in older adults. Second, improvements in muscle strength seem to be training-specific. Eccentric training was superior in increasing peak eccentric and isometric torque, while concentric training produced the biggest gains in concentric torque. The specificity of the results is in line with previous studies comparing the different effects of eccentric and concentric training (Seger – Arvidsson – Thorstensson 1998). Although eccentric training was also effective in increasing concentric strength, albeit not as effective as concentric training, it is reasonable to think that it is a viable training method for older adults with limited energy reserves. One could also consider the possibility of rehabilitating older adults with eccentric training, after which continuing with traditional resistance training once muscle strength is on a sufficient level.

If an older adult is healthy and has sufficient muscle strength, is there a reason to use an eccentric-focused training protocol in lieu of a traditional resistance training program to maintain muscle strength? Traditional resistance training includes both concentric and eccentric movements, so why would it be necessary to remove the concentric element from this training? The answer for this type of healthy older population may be to focus on both eccentric and concentric parts of the exercise, because many trainees neglect the eccentric part of the movement, thus removing the positive effect of the eccentric movement. The different techniques in performing eccentric movements might also be an explaining factor in the variability of the results. Some older participants responded very well to eccentric training, while others did not. Individual anthropometry and muscle quality might further affect the response of any method of exercise.

While resistance training is recommended for older adults in the Finnish national guidelines (Tarnanen *et al* 2010), there is limited information of the effects of concentric versus eccentric training protocols. Older adults preserve the ability to produce eccentric strength more efficiently than concentric and isometric strength. Compared to young adults, older adults also show a greater relative residual force enhancement after an eccentric contraction. However, all forms of strength are important in maintaining and improving the movement ability in older adults. The capacity of older adults to operate on higher relative levels of tension during eccentric movements and during the following concentric movement may imply greater benefits from eccentrically focused training protocols. This is also likely to improve the overall movement quality through strength development.

The practicality of eccentric-focused training programs must be considered with regard to the trainee and the desired outcome. Eccentric focused training programs can be executed purely without concentric movement, or with an increased resistance on the eccentric part of the movement. Is the trainee exercising alone or with a trainer or a therapist? Executing purely eccentric contractions of a specific muscle group may require the aid of another person or by concentric compensation from another muscle group. Specialized equipment, such as eccentric ergometers, are also effective and easy to use without aid. Whichever method is used, one must consider safety and reasonability when working with older adults. Individual responses to different training methods vary to a large degree. Monitoring the resistance levels and progress of strength development is crucial to ensure that the trainee is responding properly to the training.

A valuable finding from the literature is also that nine studies found traditional resistance training or concentric ergometer training effective in increasing some form of muscle strength. While the effectiveness of traditional resistance training is well documented, eccentric-focused training does not seem unanimously superior in increasing general muscle strength compared to traditional or concentric-focused training. Different training interventions seem to produce different responses in strength development. It is up to the aging trainee and the therapist to decide what kind of development is sought and what method could provide the best benefits.

Muscle strength is an essential part of every physiotherapists work. Whether it is the ability to walk, prevention of injuries or diaphragm activation to optimize breathing, muscle strength plays a relevant part in the clinical setting. Physiotherapists often work with people with injuries, disabilities or diminished physical functioning. Eccentric training has been an effective tool in rehabilitating tendinopathies (Sussmilch-Leitch – Collins – Bialocerkowski – Warden – Crossley 2012), but its effectiveness in increasing physical functioning through muscle strength in not as well known. Alongside increases in muscle strength, studies reviewed in this thesis found eccentric training to induce improvements in balance and stair descending abilities (LaStayo – Ewy – Pierotti – Johns – Lindstedt 2003), stair ascending and descending abilities (Symons – Vandervoort – Rice – Overend – Marsh 2005) and the six-minute walk distance test (LaStayo – Marcus – Dibble – Smith – Beck 2011). However, other studies found concentric or traditional resistance training interventions as effective or more effective than eccentric training on functional parameters such as the six-minute walk distance test, walking speed and stair descending abilities (Dias *et al* 2015; Raj – Bird – Westfold – Shield 2012; Leszczak – Olson – Stafford – Brezzo 2013).

Physiotherapists must also consider the preventive value of muscle strength. Increasing and maintaining muscle strength in old age may prevent the occurrence of many injuries and ailments. Strength of the knee extensors and lower limb musculature may improve balance and reduce fall risk in older adults (Pijnappels – Van Der Burg – Reeves – Van Dieen 2008). Although resistance training has been shown to improve lower limb muscle strength, many older adults have diminished energy reserves and may have concurrent cardiovascular diseases limiting exercise intensity and volume. Thus, eccentric-focused training may be ideal for this demographic if options of traditional exercise interventions are limited.

The practical applications of eccentric training that can be utilized by a physiotherapist depend on the resources and equipment of the clinical setting. An inexpensive method is a stair descending exercise that has also been used by Theodorou *et al* (2013) in one of the reviewed studies. However, this would require the use of an elevator to be able to remove the concentric stair ascending movement. Physiotherapists can also manually help the trainee perform eccentric movement by applying increased resistance in the eccentric phase, or decrease the resistance in the concentric phase. Specialized equipment is the least inexpensive option, but the possibility of using eccentric ergometers as the one in a study by LaStayo *et al* (2003) is an effective tool that can effortlessly be used by the trainee without assistance.

Although this review had its focus on muscle strength, muscle size and quality are also important factors in the prevention of sarcopenia. With regard to the reasons described in chapter 2.2, the changes in muscle mass can only partly explain changes in muscle strength. Sarcopenia has diminishing effects on all aging humans, but the effects are distributed differently between the sexes. According to Janssen *et al* (2000), women on average have 40% less muscle mass than men in the upper body, while the difference in the lower body is only 33%. While lower body muscle mass is undoubtedly a major determinant in mobility, one must consider effective ways to counteract the effects of sarcopenia on upper body musculature of older women.

Strengths of this review - in the author's opinion - include the scaling of the subjects to adults over 60 years of age and the specificity of the reviewed outcome. However, the heterogeneity of the selected studies limits the quality of comparative analysis. In the author's opinion the results are easiest to recapitulate in similarly designed studies, i.e. outcome is measured for the same muscle group with a similar method. A large portion of the reviewed studies did in fact assess strength with an isokinetic dynamometer, which has an excellent reliability (McCleary – Andersen 1992). The use of isokinetic dynamometry is also valuable in distinguishing the different effects on eccentric, isometric and concentric strength.

Future research of the dose-response relationships on eccentric training by older adults may provide further insight into efficient volume and intensity of eccentric training programs. Reasonable progressions in volume and intensity are necessary to prevent DOMS and other injuries, factors to which that older adults may be susceptible. When properly designed, eccentric training is an effective and safe training protocol that is well accepted in the older population.

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