

ANNI RAVA

Associations between body composition,  
mobility and blood inflammatory  
biomarkers with physical activity  
in healthy older women





**ANNI RAVA**

Associations between body composition,  
mobility and blood inflammatory  
biomarkers with physical activity  
in healthy older women



Institute of Sport Sciences and Physiotherapy, Faculty of Medicine, University of Tartu, Estonia.

Dissertation was accepted for the commencement of the Degree of Doctor of Philosophy in Exercise and Sport Sciences on September 2, 2019 by the Council of the Institute of Sport Sciences and Physiotherapy, University of Tartu, Estonia.

Supervisors: Professor Jaak Jürimäe, PhD, University of Tartu, Tartu, Estonia  
Professor Mati Pääsuke, PhD, University of Tartu, Tartu, Estonia

Opponent: Professor Arvydas Stasiulis, PhD, Lithuanian Sports University, Kaunas, Lithuania

Commencement: Senate Room of the University of Tartu, Ülikooli St. 18, Tartu on October 18, 2019, at 12 p.m.

ISSN 1406-1058  
ISBN 978-9949-03-174-0 (print)  
ISBN 978-9949-03-175-7 (pdf)

Copyright: Anni Rava, 2019

University of Tartu Press  
[www.tyk.ee](http://www.tyk.ee)

# CONTENTS

ABBREVIATIONS .....	7
LIST OF ORIGINAL PUBLICATIONS .....	8
1. INTRODUCTION .....	9
2. REVIEW OF THE LITERATURE .....	11
2.1 Aging-related changes in mobility .....	11
2.2 Muscle strength and quality in aging .....	13
2.3 Body composition in aging .....	15
2.4 Inflammatory biomarkers in aging .....	17
3. AIM AND PURPOSE OF THE STUDY .....	19
4. METHODS .....	20
4.1 Participants and experimental design .....	20
4.2 Anthropometry and body composition measurements .....	21
4.3 Measurements of skeletal muscle strength, quality and power .....	22
4.4 Measurements of mobility .....	22
4.5 Physical activity assessments .....	23
4.6 Blood analysis .....	23
4.7 Statistical analysis .....	24
5. RESULTS .....	25
5.1 Comparison of body composition, neuromuscular performance, and mobility in regularly exercising and inactive older women .....	25
5.2 Associations of distinct levels of physical activity with mobility in healthy older women .....	28
5.3 Associations of inflammatory biomarkers with objectively measured physical activity in healthy older women .....	32
6. DISCUSSION .....	35
6.1 Comparison of body composition, neuromuscular performance, and mobility in regularly exercising and inactive older women .....	35
6.2 Associations of distinct levels of physical activity with mobility in healthy older women .....	37
6.3 Associations of inflammatory biomarkers with objectively measured physical activity in healthy older women .....	39
6.4 Limitations and strengths .....	41
7. CONCLUSIONS .....	43
8. REFERENCES .....	44
SUMMARY IN ESTONIAN .....	54
ACKNOWLEDGEMENTS .....	57

PUBLICATIONS .....	59
CURRICULUM VITAE .....	90
ELULOOKIRJELDUS .....	91

## ABBREVIATIONS

6MWT	six-minute-walk test
ALM	appendicular lean mass
ALMI	appendicular lean mass index
AMQ	upper limbs muscle quality
BMD	bone mineral density
BMI	body mass index
CMJ	countermovement jump
CRP	C-reactive protein
FFM	fat free mass
FM	fat mass
FTSTS	five-times-sit-to-stand test
HGS	handgrip strength
LBM	lean body mass
LES	leg extensor muscle strength
LMQ	lower limbs muscle quality
LPA	light physical activity
MPA	moderate physical activity
MVPA	moderate-to-vigorous physical activity
PA	physical activity
RFD	rate of force development
RMM	relative muscle mass
TNF- $\alpha$	tumor necrosis factor-alpha
TUG	timed-up-and-go test
VPA	vigorous physical activity

## LIST OF ORIGINAL PUBLICATIONS

- I. **Rava A**, Pihlak A, Ereline J, Gapeyeva H, Kums T, Purge P, Jürimäe J, Pääsuke M. Body composition, neuromuscular performance, and mobility: comparison between regularly exercising and inactive older women. *Journal of Aging and Physical Activity*. 2017;25(1):58–64.
- II. **Rava A**, Pihlak A, Kums T, Purge P, Pääsuke M, Jürimäe J. Associations of distinct levels of physical activity with mobility in independent healthy older women. *Experimental Gerontology*. 2018;110:209–15.
- III. **Rava A**, Pihlak A, Kums T, Purge P, Pääsuke M, Jürimäe J. Resistin concentration is inversely associated with objectively measured physical activity in healthy older women. *Aging Clinical and Experimental Research*. 2019 (In Press).

In all papers, Anni Rava had primary responsibility for protocol development, participants' enrollment, performing measurements, preliminary and final data analysis, and writing the manuscripts.



# 1. INTRODUCTION

Aging is broadly defined as the time-dependent functional recession that affects most living organisms (Srivastava, 2017), and is characterized by a progressive decline in tissue and organ function leading to an increased risk of diseases and mortality (López-Otín et al., 2013; Srivastava, 2017). Aging-related changes are linked to many chronic diseases leading to morbidity and mortality (Kennedy et al., 2014). The cause of aging is multifaceted, the characteristics accompanying aging are listed but not limited to: genomic instability, telomere attrition, epigenetic alterations, loss of proteostasis, deregulated nutrient-sensing, mitochondrial dysfunction, cellular senescence, stem cell exhaustion, and altered intercellular communication (López-Otín et al., 2013). Since aging is associated with many negative aspects of older adult's wellbeing, knowledge about the possible approaches to enhance healthy longevity are essential to contribute healthy aging.

Loss of skeletal muscle mass and function (Kallman et al., 1990; Paterson and Warburton, 2010; Strasser et al., 2009), increased share of fat mass (FM) (Pisciottano et al., 2014; St-Onge and Gallagher, 2010), decline in bone mineral density (BMD) (Bocalini et al., 2009), evolved probability of developing disturbances in balance and gait (Bullo et al., 2015), and prevalence of chronic diseases (Paterson and Warburton, 2010) are all in some extent connected to aging. In addition, low-grade elevation of inflammatory markers among older adults has been associated with a number of conditions of aging, such as cardiovascular diseases, diabetes, cognitive decline, and physical disabilities (Singh and Newman, 2011). One of the factors affecting those changes could be a decreased commitment in everyday physical activity (PA), which commonly decreases with aging (Strasser et al., 2009) as older adults are among the most sedentary segment of the society (Paterson and Warburton, 2010). It is not entirely clear to what level and amount of PA could decrease the negative aspects of aging, although the overall beneficial effect of PA on aging has been proven (Hirvensalo et al., 2000; Milanović et al., 2013).

Older adults have twice as many disabilities and four times as many physical limitations as people less than 60 years of age (Milanović et al., 2013). At the same time, it has been demonstrated that physically inactive healthy older adults have two times higher mortality risk compared with the same age physically active older adults (Hirvensalo et al., 2000). Therefore, PA could be the key component for successful aging. Rowe and Kahn (1997) have defined successful aging as a combination of three main components, such as low probability of diseases and disease related disabilities, high cognitive and physical functional capacity, and active engagement with everyday life. The more comprehensive definition for healthy aging is specified as a process, which enables older adults to take an active part in the society and enables one to live independent and high quality of life (Lana et al., 2017; López-Otín et al., 2013). Although it is not possible to prevent aging as such, PA may counteract at some

level of aging adverse physiological consequences and minimize the effect of an otherwise sedentary lifestyle (Chodzko-Zajko et al., 2009). PA has proven to be an important cofounder of healthy aging (McPhee et al., 2016), and therefore may increase active life expectancy by lowering the likelihood for progression of chronic diseases and disabling conditions (Chodzko-Zajko et al., 2009). An active lifestyle with regular PA has been associated with a decreased risk of many chronic diseases and increased longevity (Hirvensalo et al., 2000; Hupin et al., 2015). In contrast, decreased PA level has been associated with an increased risk of cardiovascular diseases in older people (Higueras-Fresnillo et al., 2017; Lachman et al., 2018), and cardiovascular diseases are noted as one of the main causes of death in older adults (Higueras-Fresnillo et al., 2017).

Studies have shown that more physically active lifestyle lowers the probability to become dependent in later life. However, there is still limited knowledge about the exact amount on PA to remain abilities needed to cope with everyday activities in later life. Accordingly, the main aim of the current dissertation was to investigate the differences in body composition, mobility and inflammatory biomarkers between groups of healthy older women with different levels of PA engagement. Another aim of the current dissertation was to find possible associations between body composition, mobility, inflammatory biomarker and PA indices among older healthy women.

## 2. REVIEW OF THE LITERATURE

### 2.1 Aging-related changes in mobility

Mobility refers to an ability to freely move, and walking is considered an integral part of mobility (Rantanen, 2013). Among older adults, high levels of functional fitness and PA are shown to reduce the risk of falling and suffering injuries, whereas an increase in sedentary behavior may result in a decrease in muscle strength and an increase in subcutaneous fat tissue (Milanović et al., 2013). These factors compromise the ability to remain physically active and decrease physical abilities among older population (Milanović et al., 2013). Even though the process of aging is natural and inevitable, an adequate level of PA may slow down the loss of functional and physical abilities, and help to maintain a healthy way of life for older adults (Milanović et al., 2013).

Mobility decreases in accordance with increasing age (Bohannon et al., 2007; Distefano et al., 2018). Aging related changes in sensory, motor and cognitive levels alter movement biomechanics, which furthermore can adversely affect balance and mobility (Chodzko-Zajko et al., 2009). Decline in mobility is generally observed in more demanding mobility tasks, such as walking longer distances or running. In the early stages of functional decline prior to the onset of task difficulty, older adults may be able to compensate deficiency in mobility by modifying their task performance and thereby maintain their function without the perception of difficulty (Rantanen, 2013).

Frailty is an adverse health condition associated with aging and is defined as a combination of five criteria, such as unintentional weight loss, self-reported exhaustion, weakness, slow walking speed and low PA (Bandeem-Roche et al., 2006; Fried et al., 2001; Singh and Newman, 2011). Impaired balance may in turn result in fear of falling and can result in reduced PA (Chodzko-Zajko et al., 2009). It has been found that reductions in PA level and functional fitness are associated with increasing age (Milanović et al., 2013). In addition, aging results in an increase in body FM, reduction of muscle strength in both upper and lower limbs and lower levels of flexibility, agility and endurance (Milanović et al., 2013). Novak and Vute (2013) highlighted the abilities that are essential for independent life in later life: upper and lower limbs muscle strength, flexibility, balance and gait. Mobility is assessed either with self-reported assessments regarding specific mobility tasks or standardized performance-based tests (Rantanen, 2013).

Five-times-sit-to-stand test (FTSTS) is used to assess dynamic balance and functional mobility (Goldberg et al., 2012), and also lower limb strength (Bohannon et al., 2007). The ability to perform sit-to-stand is a fundamental prerequisite for mobility and functional independence in older adults (Ng et al., 2015). The sit-to-stand movement becomes mechanically demanding as people get older, since it requires sufficient lower limb muscle strength and precise postural control to transfer the body's centre of support (Ng et al., 2015). Performance of sit-to-stand has been shown to be associated with muscle

strength in lower limbs, balance control, sensation and movement strategies adopted during the maneuver (Lord et al., 2002; Ng et al., 2015). Bohannon et al. (2007) demonstrated the relationship between FTSTS time and age: older adults took longer time to complete the test in comparison to younger adults. Studies with older adults have shown the association between time taken to complete the FTSTS and falls, indicating that longer FTSTS time is increasing the likelihood of experiencing falls in older age (Doheny et al., 2011; Zhang et al., 2013), and falls are known as common cause of injury and decreased functional independence in the older population (O'Sullivan et al., 2009).

Other common mobility test for older adults is timed up-and-go test (TUG), which requires both static and dynamic balance (Barry et al., 2014), and assesses mobility and locomotor performance. Test includes basic mobility skills such as rising from chair, walking, turning and sitting down (Bischoff et al., 2003). It has been found that TUG test duration increases in a stepwise fashion with decreasing mobility (Bischoff et al., 2003). TUG test does not focus on independent effects on organ impairments, such as low muscle mass, decreased balance, but interprets the interactions of these factors on the performance of activities of daily living (Bischoff et al., 2003).

Cutoff points for functional impairments are defined as FTSTS >11.4 s (Bohannon, 2006) and TUG >12 s (Maden-Wilkinson et al., 2015). Makizako et al. (2017) demonstrated that older adults with poor result in FTSTS or TUG increased significantly the likelihood of developing disability, wherein the poor result of both tests resulted the highest rate of disability. At the same time, it has been shown that PA may improve the performance of mobility tests (Freiberger et al., 2007). For example, a 16-week strength, endurance and flexibility training significantly improved the time to perform FTSTS and TUG tests among older adults (Freiberger et al., 2007).

As the independence in later life is also associated with walking longer distances and to maintain gait while doing this (Bandeem-Roche et al., 2006; Rantanen, 2013), aerobic capacity among older adults is assessed as a distance covered in six-minute walk test (6MWT). Distance covered during the 6MWT has been associated with performing everyday activities among older population (Vilaça et al., 2014). It has also been reported that distance covered during the 6MWT is inversely associated with mortality (Yazdanyar et al., 2014). Furthermore, older adults who walked less than 338 m had more than a 1.5-fold greater risk of mortality relative to those who walked at least 414 m (Yazdanyar et al., 2014). This finding is in accordance with the cutoff for functional impairments defined as 6MWT test result less than 400 m (Maden-Wilkinson et al., 2015). In a study with older women, who engaged in exercise program three times a week, 90 min exercise program for 12 weeks, a significant improvement in 6MWT distance was observed (Nakamura et al., 2007).

Older adults with mobility impairments have higher risk of mortality and loss of independence as compared to same age adults who do not have problems with mobility (Hirvensalo et al., 2000). Difficulties moving in- and outdoors, reduced walking speed and muscle strength are all associated with an increased

risk of mortality among older adults (Laukkanen et al., 1995). Hupin et al. (2015) found that engagement in moderate-to-vigorous PA (MVPA) even below recommended level reduced the mortality risk linearly with increases in PA engagement. In another study, Fielding et al. (2017) demonstrated that at least 48 min in PA increase per week could have meaningful outcome regarding physical functioning and reduction in the development of major mobility disabilities in older adults. Long term commitment in PA may be especially favorable as older adults, who had higher levels of PA in midlife had better mobility in old age compared to less PA ones (Patel et al., 2006).

In conclusion, mobility begins to deteriorate already in midlife and studies have shown that mobility decrease is associated with increasing age. Furthermore, mobility impairments are associated with becoming dependent among older adults in later life. Studies conducted so far have shown association between PA and mobility giving the possible opportunity to preserve and decline in mobility. However, the combination of physical abilities needed to cope with everyday activities in later life and their relationship with PA have not yet been thoroughly studied in older adults.

## **2.2 Muscle strength and quality in aging**

Aging is a biological process which is associated with a gradual loss of skeletal muscle mass and function (Strasser et al., 2009). The age-associated loss of lean body mass (LBM) may lead to various negative health outcomes, such as impairment of physical performance and disabilities (Spira et al., 2015). These changes may be attributed to a combination of neural and morphological factors (Clark and Manini, 2012) and also to PA, which commonly decreases with aging (Strasser et al., 2009). Muscle strength declines from age 40 years and accelerates after age 65–70 years, and the decline is more rapid in lower body compared to upper body (Chodzko-Zajko et al., 2009). Regular physical exercise has positive effects on skeletal muscle mass and muscle strength (Clark and Manini, 2012; Cruz-Jentoft et al., 2010; Daly et al., 2008), and therefore, regular exercising may be essential for older people to maintain their independence (Daly et al., 2008; Strasser et al., 2009). Physical exercise helps to reduce the loss or in some cases even maintain skeletal muscle mass (Pinto et al., 2014; Power et al., 2012), muscle strength and power output (Bocalini et al., 2009; Nascimento et al., 2014), and through maintaining strength and power output to improve balance, coordination and gait (Bullo et al., 2015; Novak and Vute, 2013), thus reducing the risk of falls and injuries in older people (Gardner et al., 2000).

Prior to a change in absolute muscle mass, muscle tissue undergoes multiple physical changes in regards to aging, which implicit in a decrease in muscle strength, such as loss of motor units, lower motor unit firing rates, greater variability in motor unit discharge and impaired excitation-contraction coupling (Francis et al., 2017). Low relative muscle mass (RMM), defined as appendi-

cular lean mass (ALM) percentage out of total body mass (Bijlsma et al., 2014) has been associated with functional impairments and furthermore physical disability (Janssen et al., 2002). Muscle health is not only dependent on muscle mass but also muscle strength and functional capacity should be accounted for (Francis et al., 2017). RMM, absolute muscle mass and muscle strength are used as diagnostic criteria for sarcopenia (Bijlsma et al., 2014). Sarcopenia is defined as slow progressive process of loss of muscle mass and strength with a risk of adverse outcomes, such as physical disability, poor quality of life and death (Santilli et al., 2014). Criteria for diagnosing sarcopenia are: low skeletal muscle mass and either low muscle strength or low muscle performance (Santilli et al., 2014). Well-described risk factors for sarcopenia include age, gender and level of PA (Bijlsma et al., 2014; Cruz-Jentoft et al., 2010; Santilli et al., 2014). It has been reported that greater overall sitting time is associated with increased risk of sarcopenia, independent of PA and other lifestyle and confounding factors in older adults (Gianoudis et al., 2015). At the same time, it has also been reported that resistance training is effective for slowing the age-related loss of skeletal muscle mass (Santilli et al., 2014). Loss of ALM, obtained by the sum of lean mass of arms and legs (McPhee et al., 2016; Pisciotto et al., 2014; Zoico et al., 2010) is also noted as a risk factor for sarcopenia (Cruz-Jentoft et al., 2010), and is often associated with low muscle strength, power output and lack of mobility (Bijlsma et al., 2014; Pisciotto et al., 2014). It is four times more likely to be weak (grip strength <16 kg) with low ALM (<15.02 kg in women) compared to higher ALM values in older adults (Cawthon et al., 2014).

There are few studies exploring the long-term effect of regular exercise to reduce aging caused changes in muscle mass and function, and it has been found that long-term physical exercise has positive effect on muscle strength (Aagaard et al., 2007; Crane et al., 2012; Novak and Vute, 2013), aerobic endurance (Crane et al., 2012; Harridge et al., 1997), flexibility and body balance (Novak and Vute, 2013), and also mobility (Visser et al., 2005). Study conducted among older women, aged 66–87 years, showed significant increase in handgrip strength (HGS) after one year of combination of strength, aerobic, balance and coordination exercises, executed twice a week (Englund et al., 2005).

Loss of muscle mass is associated with decline in muscle strength, but maintaining or gaining muscle mass does not entirely prevent aging-related decline in muscle strength (Goodpaster et al., 2006). In addition, the loss of muscle strength is much more rapid than the concomitant loss of muscle mass, suggesting the decline in muscle quality (Goodpaster et al., 2006). Muscle quality is defined as the ratio of muscle strength and corresponding limb muscle mass (Fragala et al., 2015; Pinto et al., 2014), and low muscle quality is associated with higher risk of disability in older age (Mankowski et al., 2015). Long-term recreational PA has been associated with favorable outcome for muscle quality among older adults (Barbat-Artigas et al., 2014) and in turn, better muscle quality for older adults is associated with high amount of PA (Distefano et al.,

2018). It has showed that eight-weeks of resistance training improved significantly muscle strength and quality among older women (Santos et al., 2017). In addition, another study demonstrated that both low- and high-volume strength training promoted similar improvement in muscle quality among elderly women (Radaelli et al., 2013).

As muscle strength has been associated with all-cause mortality among older population (Laukkanen et al., 1995; Metter et al., 2002) and PA may help to reduce the loss of muscle mass and muscle strength (Aagaard et al., 2007; Crane et al., 2012; Englund et al., 2005), older adults may benefit from PA to improve independence in later life (Gale et al., 2006; Hirvensalo et al., 2000). For example, HGS has been shown to predict all-cause mortality in older people, furthermore, it has been stated that the effectiveness with which muscle functions may be more important determinant of survival than muscle size (Gale et al., 2006). On the other hand, it has also been demonstrated that HGS seems to be associated with the type of PA rather than the amount of PA time per week (Mattioli et al., 2015). When type of PA was considered regarding the HGS, older adults engaged in strength training as a PA had a significantly higher mean value of HGS compared to older adults engaged in gymnasts or aerobics (Mattioli et al., 2015).

In conclusion, age related decline in muscle mass and strength is inevitable. However, regular and sufficient PA may reduce the decline and may prevent adverse effects related to insufficient muscle mass and strength in older age. Furthermore, muscle strength is also associated with mobility and by preserving muscle strength, PA may help to maintain independence in later life.

### **2.3 Body composition in aging**

Aging has been characterized by changes in body composition, which mainly includes a decrease in fat free mass (FFM) (Maltais et al., 2009) and an increase in body fat% (Toth et al., 2000), even when the body mass remains the same (Bijlsma et al., 2014). These age-related changes in body composition may be partially caused by lowered engagement in daily PA (McPhee et al., 2016). It has been found that daily PA may induce benefits on body mass index (BMI) and body FM among independent older women (Monteiro et al., 2019). Six months of resistance training for older adults improved strength, body composition, function and wellbeing (Steele et al., 2017), while 3 months of progressive resistance training among older community-dwelling older adults resulted in improvements in muscle strength and whole body FFM, however, it was noted that this training may not be sufficient to reduce whole body fat share (Binder et al., 2005).

Body composition, in more details the share of FM and FFM in adults change with increasing age due to multiple factors, such as PA, menopausal status, nutrition status and various diseases (Guo et al., 1999). There is a significant decrease in FFM and an increase in total body FM, body mass and BMI

that occur with increasing age (Guo et al., 1999). Low FFM can be improved by an increased level of PA (Guo et al., 1999). As body mass remains the same or increases, and muscle mass and strength decrease, individuals may experience mobility disorders, increased risk of falling, impaired ability to perform daily activities, and therefore, loss of independence (Bijlsma et al., 2014; Cruz-Jentoft et al., 2010; Hirvensalo et al., 2000). Greater quantity of FM and body fat% were determinants of worse functional performance among population of older women (Vilaça et al., 2014).

It has been shown that PA, age and BMI were correlated with BMD, suggesting that PA may be suitable approach for older adults to preserve bone health (Bocalini et al., 2009). Muir et al. (2013) showed that an increase in everyday steps count can help to prevent a decrease in BMD among postmenopausal women aged 75 years and over. Bone loss is one of the important characteristics during aging (Bocalini et al., 2009; Daly et al., 2008). A decline in bone mineral mass and density with aging occurs both in men and women and excessive bone loss may lead to osteoporosis (Going et al., 1994). Osteoporosis is a condition defined as a reduction in bone mineral content and density, disrupted bone microarchitecture, low bone strength and increased risk of fractures (Going et al., 1994; Muir et al., 2013; Pacifici, 1996). Osteoporosis has become a significant public health concern among older population (Going et al., 1994), and physical exercise may help to reduce the loss or in some cases even maintain BMD in older population (Bocalini et al., 2009; Chien et al., 2000). Combined weight-bearing training, twice a week for a duration of one year showed significant increments in BMD among community living older women compared to not exercising control group (Englund et al., 2005).

Objectively measured MVPA, light PA (LPA) and sedentary behavior are all associated with metabolic risk in older adults (Jefferis et al., 2016). The beneficial associations of LPA with metabolic health are encouraging for older adults for whom initiating MVPA and maintaining high intensity PA may be particularly challenging (Jefferis et al., 2016). It has been demonstrated that all MVPA was beneficial for healthier body composition irrespective of being accumulated in bouts lasting less or more than 10 min (Jefferis et al., 2016). In addition, 24-week strength training among older women reduced significantly body mass, BMI and body fat% (Bocalini et al., 2009)

A redistribution of body fat with increasing age, including shifts from the limbs to the trunk area and from subcutaneous to visceral fat depots, has been more equivocally demonstrated than age related increases in total body FM (Going et al., 1994). The significance of the increases in total body FM as well as the centralization of body FM lie in the association of excess body fat and, in particular, excess fat on the trunk region of the body with an increased risk for morbidity and mortality from chronic diseases such as coronary heart disease and diabetes (Going et al., 1994). However, the finding of higher amounts of total and truncal fatness at older ages may also be explained at least in part by age related changes in the balance between energy intake and expenditure (Going et al., 1994).



In conclusion, most of the studies investigating the associations between PA and body composition changes during aging have reported beneficial contribution of regular PA on maintaining healthy body composition. However, there are also some studies that have not found meaningful relationship between PA and body composition variables in older adults. Therefore, clear result regarding the amount of PA needed to maintain healthy body composition is lacking. Moreover, most of the studies have been focused on specific training programs, while everyday habitual PA has been less studied in healthy older adults.

## **2.4 Inflammatory biomarkers in aging**

Adiposity, described as one of the confounding body composition characteristics of aging (Toth et al., 2000), induces a state of low-grade but chronic inflammation through a release of multiple pro-inflammatory cytokines (Sallam and Laher, 2016), and aging has also been associated with higher levels of different inflammatory biomarkers (Sallam and Laher, 2016). On the other hand, higher PA has been associated with lower circulating concentrations of inflammatory cytokines, such as C-reactive protein (CRP) (Colbert et al., 2004; Geffken et al., 2001) and tumor necrosis factor-alpha (TNF- $\alpha$ ) (Colbert et al., 2004) in studies conducted among healthy elderly population. Serum CRP and TNF- $\alpha$  concentrations are both associated with a variety of chronic diseases and conditions, such as cardiovascular diseases (Tracy et al., 1997) and osteoporosis (Pacifci, 1996), which are further interrelated with increasing age (Kennedy et al., 2014). In addition, population-based study results suggested that higher levels of serum interleukin (IL)-6 and CRP increase the risk of muscle strength loss in older men and women (Schaap et al., 2006). Furthermore, another pro-inflammatory cytokine, resistin has been associated with cardiovascular diseases in elderly population (Reilly et al., 2005).

Resistin, synthesised in humans mainly by macrophages (Marcelino-Rodríguez et al., 2017) is involved in the pathological processes of cardiovascular diseases including inflammation, endothelial dysfunction, thrombosis, angiogenesis, and smooth muscle cell dysfunction (Suragani et al., 2013). Compared to other cytokines, resistin seems to assert its effects on both inflammatory and insulin signaling pathways and has been shown to have a negative effect on insulin signaling in the liver, in adipose as well as in muscle tissues (Qatanani et al., 2009). Lou et al. (2018) showed that resistin induces endoplasmic reticulum stress and increases production of reactive oxygen species. Endoplasmic reticulum stress induced by resistin may play an important role in the pathogenesis of vascular dysfunction or vascular diseases (Lou et al., 2018). Resistin has become one of the emerging biomarkers involved in pathways for adiposity, insulin resistance and inflammation (Alissa et al., 2019). Previously published studies have reported an inverse association of resistin with PA in general population (Marcelino-Rodríguez et al., 2017), in overweight cohort (Jones et al., 2009) and among postmenopausal women (Prestes et al., 2009), while no

association between PA and resistin was reported in a study with postmenopausal women with type 2 diabetes (Giannopoulou et al., 2005). Abedi et al. (2017) reported significant reduction in resistin concentration after eight weeks of aerobic training among middle-aged women. Accordingly, there are few studies composed to examine the association between resistin and PA, but none has been done with healthy physically active older adults.

Botero et al. (2013) investigated the effect of long-term periodized resistance training on body composition, muscle strength, resistin and leptin concentrations in elderly postmenopausal women. A significant increase in muscle strength and LBM, and a decrease in body fat% and FM after 12 month of resistance training was reported (Botero et al., 2013). Furthermore, resistin and leptin concentrations were also significantly lower after resistance training period (Botero et al., 2013). Circulating leptin has been described as a marker for cardiovascular diseases and also to all-cause mortality among older women (Mishra et al., 2015). Leptin has been found to be negatively associated with objectively measured PA in healthy older women (Alessa et al., 2017).

In conclusion, different studies have shown that PA reduces the levels of inflammatory markers. However, the exact mechanism for this reduction is not clear. A possible mechanism for this reduction may be related to a preferential decrease in visceral fat with PA interventions (Singh and Newman, 2011). However, to our best knowledge, there are no studies conducted to explore the associations between inflammatory cytokines with PA levels measured objectively using accelerometers in a population of healthy physically active older women.

### **3. AIM AND PURPOSE OF THE STUDY**

The general aim of this dissertation was to investigate associations between body composition, mobility and blood inflammatory biomarkers with PA among a sample of healthy older women.

The specific purposes of this study were to:

- (1) compare body composition, neuromuscular performance and mobility in healthy older women with different PA patterns, and to examine the relationship between skeletal muscle mass, strength and mobility (Paper I);
- (2) determine differences in body composition and mobility parameters among older women with various weekly MVPA levels, and to evaluate the relationship between distinct levels of PA and mobility (Paper II);
- (3) examine the associations between blood inflammatory biomarkers and objectively assessed PA in healthy older women with different levels of PA engagement (Paper III).

## 4. METHODS

### 4.1 Participants and experimental design

In total, 113 women aged between 65–91 years volunteered to participate in these studies (Table 1). Participants were recruited from the community. Advertisements were presented in local senior centers and training groups. Interested individuals completed a telephone interview before recruitment. Subjects were eligible if they were aged 65 years or older, healthy, living independently in the community and had been weight stable over the last six months. The exclusion criteria were cardiac illnesses, neurological illnesses, joint replacements or any other illnesses, which could interfere with motor functions or the ability to give informed consent (Bijlsma et al., 2014; Guadagnin et al., 2015).

**Table 1.** Descriptive data of the subjects (mean  $\pm$  SD).

	<b>n</b>	<b>Age (years)</b>	<b>Height (cm)</b>	<b>Body mass (kg)</b>	<b>BMI (kg/m<sup>2</sup>)</b>	<b>Body fat%</b>
Study I (Paper I)	32	72.1 $\pm$ 3.9	160.6 $\pm$ 5.3	69.7 $\pm$ 13.4	27.0 $\pm$ 4.7	35.4 $\pm$ 6.3
Study II (Papers II and III)	81	73.1 $\pm$ 5.3	159.8 $\pm$ 5.4	70.4 $\pm$ 12.3	27.5 $\pm$ 4.5	37.0 $\pm$ 5.5

In Study I, 32 older women who met all of the inclusion criteria were divided into two groups according to their self-reported PA history and type: regularly exercising (n=22) and inactive (n=10) older women. Regularly exercising women had been exercising at least twice a week, with a minimum of 60 min per training session for at least the last 5 years, all year round as published previously (Kemmler and von Stengel, 2013, Sillanpää et al., 2014; Stensvold et al., 2015). Regularly exercising women had trained on average of 14.6 years (range: 5–35 years), and the average age of the commencement of regular exercising was 57.3 years. Participants were defined as regularly exercising if their trainings were largely on moderate to vigorous intensity, so they experienced sweating and increased breathing rate during the exercising. Women in this group practiced in Nordic walking, running and gymnastics. Inactive women had not trained for the last 5 years or they had completed only one PA session per week, besides their usual everyday activities (Kemmler and von Stengel, 2013; McPhee et al., 2013). This one PA session did not last longer than 30 minutes (McPhee et al., 2013).

In Study II, 81 women, who met all of the inclusion criteria were allocated to three groups according to the accelerometer obtained MVPA data: highest

MVPA (H-MVPA) (n = 27), middle MVPA (M-MVPA) (n = 40) and lowest MVPA (L-MVPA) (n = 14) groups. Participants who had a sum of 150 min and more of MVPA in at least 10 min bouts were part of H-MVPA group, and participants who did not have any MVPA bouts with the duration of at least 10 min were included in L-MVPA group. All other participants (who had sum of MVPA in 10 min bouts in between 10 and 149 min) were part of M-MVPA group (Heesch et al., 2008; Yorston et al., 2012).

In Study I, in the first measurement session, anthropometrical, physical performance (HGS, lower extremity strength and power) and mobility tests were completed. Body composition and bone mineral measurements were conducted one week after the first assessment session.

In Study II, in the first measurement session, anthropometric and body composition measurements were completed. In addition, participants started seven-day accelerometer tracking after the first measurement session. Mobility tests were conducted one week after the first session, when study participants had completed seven days accelerometer tracking. Blood samples were given between the two measurements sessions.

All participants signed informed consent before any study procedures. The studies were approved by the Research Ethics Committee of the University of Tartu and conducted in accordance with Helsinki Declaration.

## **4.2 Anthropometry and body composition measurements**

Body height was measured with an inextensible and fixed vertical bar (Soehnle Professional, Germany) to the nearest 0.1 cm and body mass was measured by a medical electronic scale (Soehnle, Germany) to the nearest 0.1 kg. BMI ( $\text{kg}/\text{m}^2$ ) was calculated as body mass (kg) divided by the square of body height ( $\text{m}^2$ ). Whole body composition was measured using dual-energy X-ray absorptiometry (DXA) (Hologic Discovery QDR Series, Waltham, MA, USA). Whole-body FM was expressed in kg and as body fat%, and FFM (kg) was defined as the sum of bone mineral content (BMC) and fat free soft tissue parts (i.e., LBM). Appendicular skeletal muscle mass was quantified as a sum of upper and lower limbs lean mass (ALM, kg) (Brady et al., 2014). As an index of sarcopenia, appendicular lean mass index (ALMI,  $\text{kg}\cdot\text{m}^{-2}$ ) was calculated as ALM divided by body height squared (Baumgartner et al., 1998). In addition, ALM and BMI ratio was derived ( $\text{ALM}_{\text{BMI}}$ ) (Spira et al., 2015). RMM (%) was calculated as ALM percentage of the total body mass (Bijlsma et al., 2014).

### **4.3 Measurements of skeletal muscle strength, quality and power**

HGS was assessed with a portable handheld dynamometer (Lafayette Hand Dynamometer, Lafayette Instrument, USA). Participants were instructed to squeeze the handle as forcefully as they can. All participants performed three tests with each hand, alternating between dominant and non-dominant hand, break between two tests was approximately 30 s and the highest value was used for analysis (McPhee et al., 2013). Upper limbs muscle quality (AMQ) was calculated as the ratio between HGS and corresponding upper limbs lean mass (Vilaça et al., 2014).

Isometric leg extensor muscle strength (LES) during bilateral exertion was measured by a custom-made dynamometer. Participants were seated on a specially designed seat and participants were instructed to exert their maximal force as fast as possible and maintain for 2–3 s. A rest period of 1 min was allowed between the attempts. At least three attempts were completed and the best performance was used for the analysis (Vahtrik et al., 2014). Lower limbs muscle quality (LMQ) was calculated as the ratio of LES and sum of lower limbs lean mass (Brady et al., 2014; Vilaça et al., 2014).

Power output during countermovement vertical jump (CMJ) was tested at force platform (PD-3A, VISTI, Russia) (Pääsuke et al., 2003). CMJ started from an upright position, following preliminary downward movement by flexing at the knees and hips (eccentric contraction), then immediately extends the knees and hips again to jump vertically up off the platform (concentric contraction). The participants were safeguarded by two members of the study team during the testing of vertical jumping performance. Participants performed three attempts and highest jump and power output were taken into analysis (Pääsuke et al., 2003).

### **4.4 Measurements of mobility**

Five-times-sit-to-stand test (FTSTS) was used to assess dynamic balance and functional mobility (Goldberg et al., 2012) and lower limb strength (Bohannon et al., 2007). Participants started the test in a sitting position in a standard height adjustable chair with no armrest. Participants were instructed to cross both arms across the chest, start from the seated position, stand up and sit down 5 times in succession as fast as they could. Time from the starting position to the final standing position was recorded (Goldberg et al., 2012).

A timed up-and-go test (TUG), which requires both static and dynamics balance (Barry et al., 2014), was performed on a standard chair with no armrest. Subjects were asked to stand-up from the chair, walk straight around a cone, located 3 m ahead, return and sit down to the chair as fast as possible. Time spent on performing the test was measured (Maden-Wilkinson et al., 2015).

Aerobic capacity was assessed with 6MWT (McPhee et al., 2013; Vilaça et al., 2014). The test was performed on a 20 m circuit and participants were instructed to walk as fast as they could to cover the maximal distance possible within 6 min. Running was not allowed. Distance covered in the 6 min walk was recorded (McPhee et al., 2013; Vilaça et al., 2014).

## 4.5 Physical activity assessments

Objective physical activity (PA) was measured by accelerometer (Actigraph, Pensacola, FL, USA). Accelerometer was worn on the right hip attached by an elastic, adjustable band. Participants were instructed to wear accelerometer for seven consecutive days during waking hours and remove accelerometer only for water activities (shower, bathing, swimming) and during sleeping hours. Participants were asked to maintain regular daily activities during PA measurement period. The interval of time (epoch) used was set to 15 s, data were uploaded to a computer and analyzed afterwards. Days with <10 h accelerometer wear time were omitted from the further analysis (Foong et al., 2016), also participants with less than four days of valid accelerometer data were excluded (Freedson et al., 1998; Johansson et al., 2015). Periods  $\geq 60$  min defined <100 counts per minute (cpm) were excluded from the analysis as non-wear time (Johansson et al., 2015). Sedentary time was characterized <100 cpm, light PA (LPA) 100–1951 cpm, moderate PA (MPA) 1952–5724 cpm and vigorous PA (VPA)  $\geq 5725$  cpm (Gorman et al., 2014; Johansson et al., 2015). MVPA was classified as the sum of MPA and VPA time in min.

Weekly MVPA was used to differentiate those with sufficient PA to meet the recommended amount of  $\geq 150$  min $\cdot$ wk $^{-1}$  of MVPA (Loprinzi et al., 2015) in bouts of at least 10 min from those who did not (Gennuso et al., 2013), with allowance for interruptions of 1–2 min (Hansen et al., 2012). For individuals with less than seven days of valid accelerometer data, derived mean MVPA per day (22 min $\cdot$ day $^{-1}$ ) was used to assess if the recommended amount of MVPA was reached (Dohrn et al., 2016). Such an approach allows having longer bouts of PA on some days and less active on other and still meet the PA recommendations (Hansen et al., 2012).

## 4.6 Blood analysis

Blood samples were obtained from the vein before breakfast, between 8 a.m. and 9 a.m. after an overnight fast. The blood serum was separated and then frozen at  $-20$  °C for further analysis. Using a commercial ELISA kit (Quantikine® R&D Systems, Minneapolis, USA), leptin, resistin, CRP and TNF- $\alpha$  were measured according to the manufacturer's instructions as described previously (Bucci et al., 2013).

## 4.7 Statistical analysis

All analyses were conducted using SPSS for Windows version 20.0. Descriptive statistics were expressed as the means and standard deviations ( $\pm$  SDs). The Kolmogorov-Smirnov test was used to determine whether the parameters had normal distribution. Variables that were not normally distributed were log transformed and rechecked for normality. In Study I, Student's independent t-test was used for determination of significant differences between groups. Differences between groups were considered significant at  $p < 0.05$ . For assessing clinical significance between groups, effect size (ES) and minimal important difference (MID) were found. Differences between groups were considered clinically significant if both conditions were met:  $ES > 0.4$  and MID was lower than the mean difference between studied groups (Armijo-Olivo et al, 2011). In Study II, one-way ANOVA with Games-Howell post-hoc tests were used to compare outcome variables between studied groups, assuming non-equal variances between groups. Bonferroni method was used to counteract the problem of multiple comparison and statistical significance for between group comparison was set to  $p < 0.0025$ . Pearson correlation coefficients were used to determine possible relationships between different measures. In Study I, to correct for multiple testing, the p-value for correlations had to be  $p < 0.0004$  to be considered significant. In Study II, additionally, partial correlation analysis was performed, while controlling for age and BMI. Stepwise multiple regression analysis was used to determine the relative contribution of a group of independent variables on the dependent variables. Due to number of tests were carried out without preplanned hypotheses, Bonferroni method was used to avoid type I error due to multiple comparisons. Statistical significance for correlations was set to  $p < 0.00625$ . Adjustments were done considering the number of tests involved in the analysis.



## 5. RESULTS

### 5.1 Comparison of body composition, neuromuscular performance, and mobility in regularly exercising and inactive older women

Participants characteristics are displayed in Table 2 (Paper I). Inactive women had higher values for body mass ( $p=0.0465$ ;  $ES=0.79$ ), BMI ( $p=0.0210$ ;  $ES=0.93$ ), body fat% ( $p=0.0035$ ;  $ES=1.21$ ) and FM ( $p=0.0091$ ;  $ES=1.06$ ) in comparison with regularly exercising women. Regularly exercising older women had significantly higher values for LES ( $p=0.0091$ ;  $ES=1.06$ ) and LES adjusted with body mass ( $p=0.0003$ ;  $ES=1.57$ ), and also for RMM ( $p=0.0017$ ;  $ES=1.32$ ) and LMQ ( $p=0.0046$ ;  $ES=1.17$ ). There was no statistical difference for HGS or AMQ, although AMQ value was clinically different ( $ES=0.59$ ) between regularly exercising and inactive women. Values for ALM and ALMI did not differ in regularly exercising and inactive older women ( $p>0.05$ ). Also values for RFD and power output during CMJ did not differ significantly ( $p>0.05$ ) between the studied groups. However, CMJ power was clinically different ( $ES=-0.57$ ), considering higher values for inactive women. For mobility parameters, regularly exercising older women covered significantly longer distances in 6MWT ( $p=0.0088$ ;  $ES=1.07$ ) and performed FTSTS in shorter time ( $p=0.0014$ ;  $ES=1.34$ ). Time for performing TUG did not differ significantly ( $p>0.05$ ) between regularly exercising and inactive healthy older women.

**Table 2.** Mean ( $\pm$  SD) anthropometric, body composition, neuromuscular performance and mobility characteristics in the older women with different physical activity pattern.

	Regularly exercising (n=22)	Inactive (n=10)
Age	71.9 $\pm$ 4.4	72.7 $\pm$ 2.7
<b>Anthropometric and body composition indices</b>		
Height (cm)	160.7 $\pm$ 5.6	160.2 $\pm$ 4.8
Body mass (kg)	66.5 $\pm$ 13.1	76.6 $\pm$ 12.0*
BMI (kg/m <sup>2</sup> )	25.7 $\pm$ 4.6	29.8 $\pm$ 3.8*
Body fat%	33.3 $\pm$ 5.8	40.0 $\pm$ 4.9*
FFM (kg)	43.38 $\pm$ 6.59	45.27 $\pm$ 6.81
LBM (kg)	41.37 $\pm$ 6.39	43.18 $\pm$ 6.46
FM (kg)	22.39 $\pm$ 8.00	30.52 $\pm$ 6.79*
BMC (kg)	2.01 $\pm$ 0.28	2.09 $\pm$ 0.41
BMD (g/cm <sup>2</sup> )	1.05 $\pm$ 0.10	1.04 $\pm$ 0.11
ALM (kg)	17.64 $\pm$ 2.80	17.90 $\pm$ 2.68
ALMI (kg/m <sup>2</sup> )	6.8 $\pm$ 0.9	7.0 $\pm$ 0.8
Relative muscle mass (%)	26.9 $\pm$ 2.5	23.5 $\pm$ 2.4*

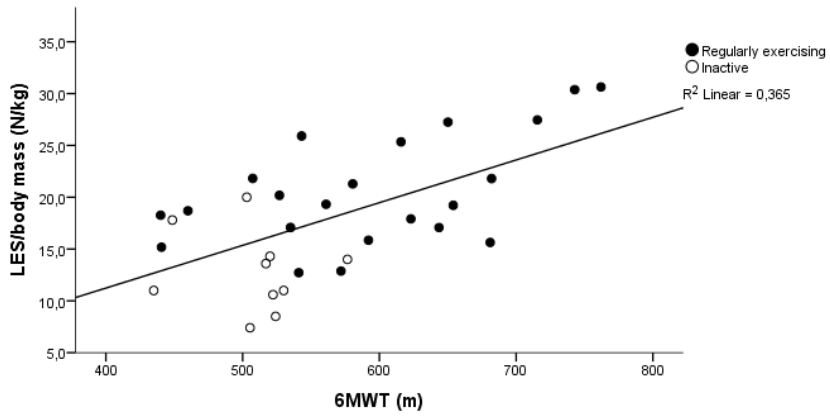
	<b>Regularly exercising (n=22)</b>	<b>Inactive (n=10)</b>
<b>Muscle strength, power and quality indices</b>		
HGS (kg)	30.1 ± 4.8	30.5 ± 6.8
LES (N)	1346 ± 352	977 ± 334*
LES/body mass (N/kg)	20.5 ± 5.3	12.8 ± 4.0*
RFD 0.2 s (N/s)	3777 ± 2127	3066 ± 1661
CMJ power (W)	1438.5 ± 321.7	1612.3 ± 356.6
CMJ power/body mass (W/kg)	22.0 ± 4.7	21.0 ± 2.9
AMQ (kg/kg)	15.9 ± 2.6	14.5 ± 1.8
LMQ (N/kg)	97.0 ± 23.6	70.4 ± 20.7*
<b>Mobility indices</b>		
6MWT (m)	594.1 ± 92.3	508.2 ± 40.5*
FTSTS (s)	8.6 ± 1.4	10.4 ± 1.5*
TUG (s)	6.0 ± 1.1	6.1 ± 0.7

\* p<0.05 compared with regularly exercising women

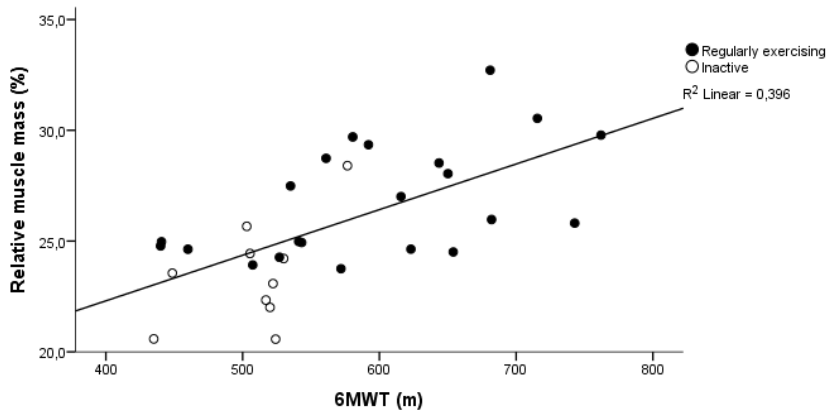
BMI – body mass index; FFM – fat free mass; LBM – lean body mass; FM – fat mass; BMC – bone mineral content; BMD – bone mineral density; ALM – appendicular lean mass; ALMI – appendicular lean mass index; HGS – handgrip strength; LES – leg extensor muscle isometric strength; CMJ – countermovement jump; RFD – rate of force development of the leg extensor muscles, 0.2 s onset exertion; 6MWT – six-minute walk test; FTSTS – five-times-sit-to-stand test; TUG – timed up-and-go test; AMQ – upper limbs muscle quality; LMQ – lower limbs muscle quality

For overall group (Paper I), distance covered in 6MWT had positive correlation with LES per unit of body mass ( $p=0.0002$ ; Figure 1A), RFD of leg extensor muscles ( $p=0.0003$ ; Figure 1B) and RMM ( $p=0.0001$ ; Figure 1C). There was negative relationship between time to perform TUG and power output during CMJ adjusted with body mass ( $p=0.0001$ ; Figure 2). FTSTS was not significantly related ( $p>0.0004$ ) to body composition parameters nor physical function measurements. In addition, no correlations were observed between mobility parameters and muscle mass and function indices ( $p>0.0004$ ).

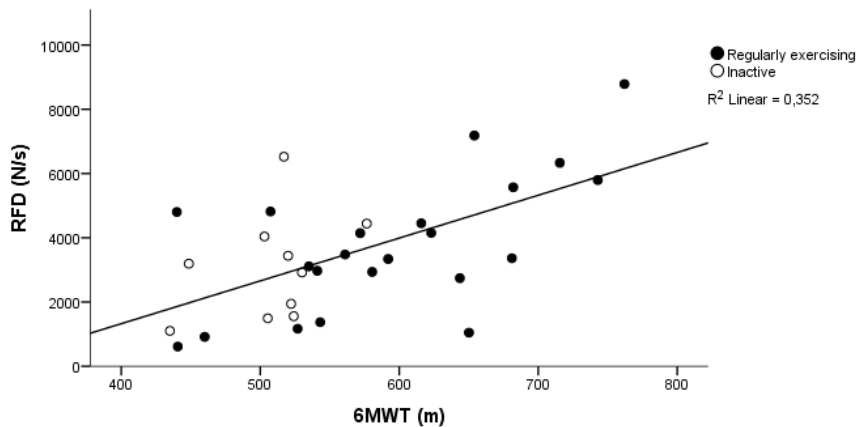
A



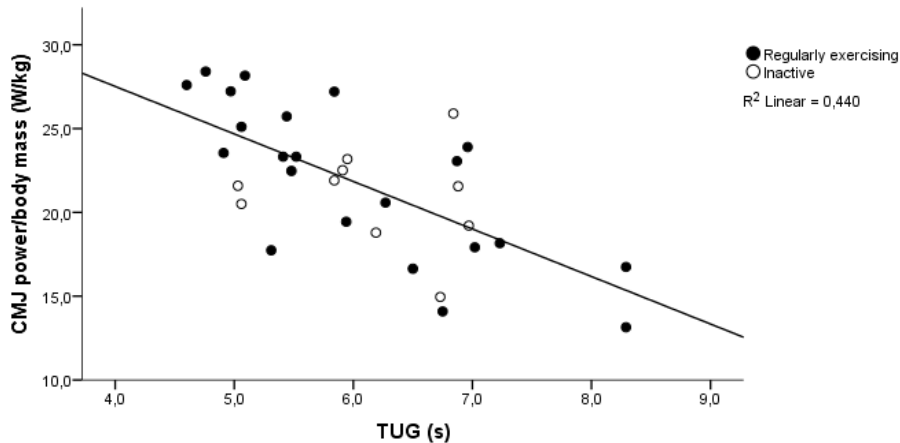
B



C



**Figure 1.** The relationships between distance covered in six-minute walk test (6MWT) and A – leg extensor muscle strength (LES) adjusted with body mass, B – relative muscle mass and C – rate of force development (RFD) of the leg extensor muscles in healthy older women (n=32).



**Figure 2.** The relationship between time performing up and go test (TUG) and power output during countermovement jump (CMJ) per unit of body mass (n=32).

## 5.2 Associations of distinct levels of physical activity with mobility in healthy older women

Participants characteristics are displayed in Table 3 (Paper II). No differences in body composition parameters were observed between studied groups ( $p > 0.0025$ ). For mobility parameters, women in L-MVPA covered significantly shorter distances in 6MWT and took longer time to perform FTSTS and TUG compared to women in M-MVPA (6MWT  $p=0.003$ ; FTSTS  $p=0.009$ ) and H-MVPA (6MWT  $p=0.000$ ; FTSTS  $p=0.006$ ; TUG  $p=0.003$ ) groups. Mobility test results did not differ between women in H-MVPA and M-MVPA groups ( $p > 0.0025$ ). Steps per day ( $p=0.000$ ), MPA ( $p=0.000$ ) and MVPA ( $p=0.000$ ) were different between H-MVPA and M-MVPA groups and between H-MVPA and L-MVPA groups (steps per day  $p=0.000$ ; MPA  $p=0.000$ ; MVPA  $p=0.000$ ). In addition, MPA ( $p=0.000$ ) and MVPA ( $p=0.000$ ) were different between M-MVPA and L-MVPA groups. There were no differences ( $p > 0.0025$ ) in sedentary, LPA and VPA time per day between studied groups.

**Table 3.** Participants characteristics (mean  $\pm$  SD)

	<b>Highest MVPA (n=27)</b>	<b>Middle MVPA (n=40)</b>	<b>Lowest MVPA (n=14)</b>
Age (years)	72.5 $\pm$ 4.5	72.5 $\pm$ 5.0	76.0 $\pm$ 7.1
<b>Body composition</b>			
Height (cm)	160.7 $\pm$ 4.9	159.4 $\pm$ 5.3	159.3 $\pm$ 5.4
Body mass (kg)	68.5 $\pm$ 13.9	69.3 $\pm$ 9.6	77.2 $\pm$ 14.4
BMI (kg/m <sup>2</sup> )	26.5 $\pm$ 5.2	27.26 $\pm$ 3.5	30.3 $\pm$ 4.9
Body fat %	34.8 $\pm$ 6.5	37.2 $\pm$ 4.2	40.5 $\pm$ 5.2
FFM (kg)	40.39 $\pm$ 6.37	42.60 $\pm$ 5.00	44.67 $\pm$ 7.13
FM (kg)	24.10 $\pm$ 8.62	25.59 $\pm$ 5.69	31.1 $\pm$ 8.58
ALM (kg)	17.48 $\pm$ 2.61	17.12 $\pm$ 2.31	17.92 $\pm$ 2.81
ALMI (kg/m <sup>2</sup> )	6.75 $\pm$ 0.85	6.73 $\pm$ 0.75	7.03 $\pm$ 0.77
ALM <sub>BMI</sub> (ratio)	0.67 $\pm$ 0.11	0.63 $\pm$ 0.08	0.60 $\pm$ 0.08
RMM (%)	25.9 $\pm$ 3.45	24.81 $\pm$ 2.19	23.49 $\pm$ 2.63
<b>Mobility</b>			
TUG (s)	5.7 $\pm$ 0.6	5.9 $\pm$ 0.8	6.8 $\pm$ 1.0 <sup>a</sup>
FTSTS (s)	9.1 $\pm$ 1.4	9.3 $\pm$ 1.8	11.7 $\pm$ 2.5 <sup>ab</sup>
6MWT (m)	587.8 $\pm$ 65.4	547.0 $\pm$ 74.3	462.4 $\pm$ 71.9 <sup>ab</sup>
<b>Physical activity</b>			
Steps (per day)	11855 $\pm$ 2927	8329 $\pm$ 2490 <sup>a</sup>	6233 $\pm$ 2292 <sup>a</sup>
Sedentary (min/day)	623.7 $\pm$ 120.6	602.4 $\pm$ 101.1	579.2 $\pm$ 92.9
LPA (min/day)	245.8 $\pm$ 62.4	264.3 $\pm$ 65.1	281.1 $\pm$ 92.1
MPA (min/day)	79.3 $\pm$ 27.8	48.3 $\pm$ 18.9 <sup>a</sup>	25.0 $\pm$ 16.4 <sup>ab</sup>
VPA (min/day)	3.6 $\pm$ 10.2	0.5 $\pm$ 1.1	0.3 $\pm$ 0.3
MVPA (min/day)	83.0 $\pm$ 25.8	48.9 $\pm$ 19.0 <sup>a</sup>	25.3 $\pm$ 16.6 <sup>ab</sup>

<sup>a</sup> p < 0.0025 significantly different from highest MVPA

<sup>b</sup> p < 0.0025 significantly different from middle MVPA

BMI – body mass index, FFM – fat free mass, FM – fat mass, ALMI – appendicular lean mass index, ALM<sub>BMI</sub> – appendicular lean mass and body mass index ratio, RMM – relative muscle mass, TUG – timed up-and-go test, FTSTS – five-time-sit-to-stand test, 6MWT – six-minute walk test, LPA – light physical activity, MPA – moderate physical activity, VPA – vigorous physical activity, MVPA – moderate-to-vigorous physical activity

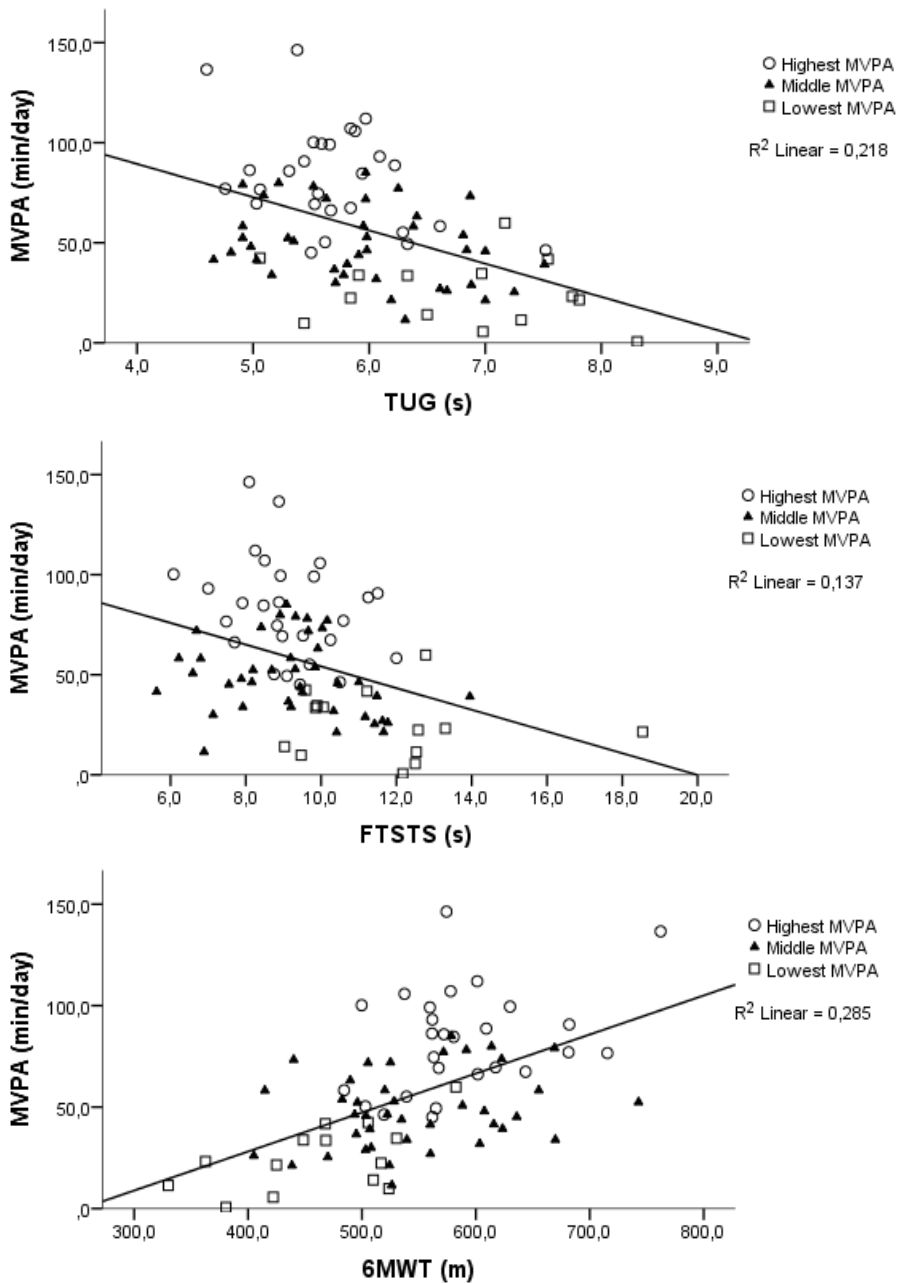
Relationships between distinct levels of PA and mobility are presented in Table 4 (Paper II). For overall group, time to perform TUG had a negative association with MPA ( $p=0.0001$ ) and MVPA ( $r=-0.47$ ;  $p=0.0000$ ) (Figure 3) (Paper II). Relationships between time to perform TUG and MPA ( $p=0.0040$ ) and MVPA ( $r=-0.34$ ;  $p=0.0022$ ) remained significant after controlling for age and BMI. FTSTS was negatively correlated with MPA ( $p=0.0014$ ) and MVPA ( $r=-0.37$ ;  $p=0.0007$ ). However, relationship between FTSTS and MPA ( $p>0.00625$ ) and MVPA ( $r=-0.27$ ;  $p>0.00625$ ) were no longer significant after controlling for age and BMI. Distance covered in 6MWT was positively correlated with MPA ( $p=0.0001$ ), VPA ( $p=0.0014$ ) and MVPA ( $r=0.53$ ;  $p=0.0000$ ) (Figure 3), and MPA ( $p=0.0030$ ) and MVPA ( $r=0.39$ ;  $p=0.0003$ ) remained significantly associated also after controlling for age and BMI.

**Table 4.** Relationships between distinct levels of physical activity and mobility. Partial correlation coefficients controlling for age and BMI presented in brackets.

	Sedentary (min/day)	LPA (min/day)	MPA (min/day)	VPA (min/day)
TUG (s)	0.14 (0.10)	-0.12 (-0.11)	-0.43* (-0.32*)	-0.19 (-0.08)
FTSTS (s)	0.07 (0.05)	-0.12 (-0.12)	-0.35* (-0.26)	-0.13 (-0.06)
6MWT (m)	-0.22 (-0.21)	0.04 (0.02)	0.47* (0.33*)	0.35* (0.28)

\*  $p<0.00625$  – significant correlation

TUG – timed up-and-go test, FTSTS – five-times-sit-to-stand test, 6MWT – six-minute walk test, LPA – light physical activity, MPA – moderate physical activity, VPA – vigorous physical activity



**Figure 3.** Moderate-to-vigorous physical activity (MVPA) time per day relationships with time performing timed up and go test (TUG), five-times-sit-to-stand test (FTSTS) and six-minute walk test (6MWT) (n=81).

Stepwise linear regression analyses were conducted where each studied mobility test (TUG, FTSTS and 6MWT) was a dependent variable and the independent variables inserted were different levels of PA. The analyses showed that MVPA was the strongest independent predictor for each mobility test (Table 5) (Paper II). MVPA explained 21.7% of the variance in TUG, 13.7% of the variance in FTSTS and 28.5% of the variance in 6MWT. Moreover, MVPA and VPA together explained 35.5% of the variance in 6MWT.

**Table 5.** Independent predictors for mobility parameters from multiple stepwise linear regression analyses.

		$\beta$	SE	p-value	R <sup>2</sup>
<b>TUG</b>	MVPA (min/day)	-0.13	0.003	0.000	0.217
<b>FTSTS</b>	MVPA (min/day)	-0.25	0.007	0.000	0.137
<b>6MWT</b>	MVPA (min/day)	1.48	0.264	0.000	0.285
<b>6MWT</b>	MVPA (min/day)	1.35	0.257	0.000	0.355
	VPA (min/day)	3.62	1.246	0.005	

MVPA – moderate-to-vigorous physical activity, VPA – vigorous physical activity, TUG – timed up-and-go test, FTSTS – five-times-sit-to-stand test, 6MWT – six-minute walk test

### 5.3 Associations of inflammatory biomarkers with objectively measured physical activity in healthy older women

Mean participants characteristics and PA indices are presented in Table 3, mean blood biomarker values by group are presented in Table 6 (Paper III). There were no differences between groups for resistin, leptin, TNF- $\alpha$  and for CRP concentrations, however higher MVPA groups tended (resistin: p=0.098; leptin: p=0.021; CRP: p=0.044) to have lower level of studied blood biomarker concentrations.

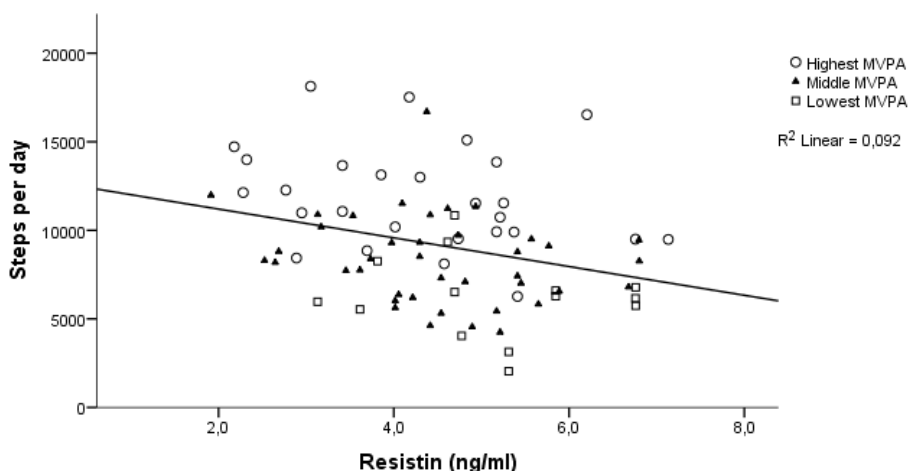
**Table 6.** Blood biomarker values by group (mean  $\pm$  SD).

	Highest MVPA (n=27)	Middle MVPA (n=40)	Lowest MVPA (n=14)	Overall (n=81)
Resistin (ng/ml)	4.29 $\pm$ 0.26	4.54 $\pm$ 0.20	5.31 $\pm$ 0.39	4.59 $\pm$ 1.37
Leptin (ng/ml)	21.41 $\pm$ 3.86	22.51 $\pm$ 2.04	30.04 $\pm$ 3.28	23.45 $\pm$ 1.74
TNF- $\alpha$ (pg/ml)	3.37 $\pm$ 0.27	3.47 $\pm$ 0.19	3.34 $\pm$ 0.19	3.42 $\pm$ 0.13
CRP (mg/l)	1.67 $\pm$ 0.34	1.53 $\pm$ 0.21	2.26 $\pm$ 0.30	1.71 $\pm$ 0.16

MVPA – moderate-to-vigorous physical activity, TNF- $\alpha$  – tumor necrosis factor alpha, CRP – C-reactive protein



For overall group, there was a significant negative relationship between resistin and count of steps per day ( $p=0.005$ ) (Figure 4) (Paper III). Association remained significant after controlling for age ( $p=0.006$ ). There was no relationship between resistin and sedentary time ( $r=-0.024$ ;  $p=0.830$ ), LPA ( $r=0.115$ ;  $p=0.305$ ) or MVPA ( $r=-0.269$ ;  $p=0.015$ ). For leptin there were no association with steps per day ( $r=-0.251$ ;  $p=0.024$ ), sedentary time ( $r=0.060$ ;  $p=0.596$ ), LPA ( $r=0.036$ ;  $p=0.749$ ) or MVPA ( $r=-0.276$ ;  $p=0.013$ ). However, there was inverse association between leptin and MVPA only after controlling for age ( $p=0.006$ ). No association were found between TNF- $\alpha$  and steps per day ( $r=0.011$ ;  $p=0.925$ ), sedentary time ( $r=0.150$ ;  $p=0.182$ ), LPA ( $r=-0.048$ ;  $p=0.671$ ) or MVPA ( $r=-0.005$ ;  $p=0.966$ ). Furthermore, there were no relationship between CRP concentration and steps per day ( $r=-0.183$ ;  $p=0.102$ ), sedentary time ( $r=0.014$ ;  $p=0.904$ ), LPA ( $r=0.161$ ;  $p=0.152$ ) and MVPA ( $r=-0.280$ ;  $p=0.011$ ).



**Figure 4.** Associations between steps per day and resistin in healthy older women ( $n=81$ ). MVPA – moderate-to-vigorous physical activity

In multivariate stepwise linear regression (Table 7) (Paper III), each blood biomarker was added as a dependent variable and independent variables inserted were PA indices: steps per day, sedentary time, LPA, MPA, VPA and MVPA, in addition age and FM were added. Analyses showed that steps per day was the strongest independent predictor for resistin, explaining 8.9% ( $R^2 \times 100$ ) of the variance, whereas for leptin, TNF- $\alpha$  and CRP, the strongest independent predictor was FM.

**Table 7.** Independent predictors for mobility parameters from multiple stepwise linear regression analyses.

		<b><math>\beta</math></b>	<b>SE</b>	<b>p-value</b>	<b>R<sup>2</sup></b>
<b>Resistin</b>	Steps per day	-0.014	0.005	0.008	0.089
<b>Leptin</b>	FM	1.492	0.161	0.000	0.522
<b>TNF-<math>\alpha</math></b>	FM	0.037	0.017	0.008	0.056
<b>CRP</b>	FM	0.110	0.018	0.000	0.326

TNF- $\alpha$  – tumor necrosis factor alpha, CRP – C-reactive protein, FM – fat mass

## 6. DISCUSSION

### 6.1 Comparison of body composition, neuromuscular performance, and mobility in regularly exercising and inactive older women

This study (Paper I) evaluated the differences in body composition, neuromuscular performance and mobility in regularly exercising and inactive healthy older women, and also the relationships between skeletal muscle mass, strength and mobility. The results show that regularly exercising women had higher values for RMM, LES and mobility, and also lower FM. Isometric strength and power output of the leg extensor muscles adjusted with body mass associated with mobility among healthy older women with different PA pattern. The main finding of this study indicates that long-term regular exercising could decrease age-related changes in lower extremity muscle strength and mobility, therefore favors maintaining the independence in healthy older women.

In our study, regularly exercising women had significantly higher value for LES compared to inactive women, furthermore value for LES adjusted with body mass was one-third higher in regularly exercising women compared to inactive women. Muscle strength declines between the ages of 50–60 years annually 1–1.5% and after that 3% per year (Legrand et al., 2013). Lower muscle strength is associated with higher mortality risk among older population (Newman et al., 2006). Crane et al. (2012) state similar results which show that long-term aerobic exercise has beneficial impact on maintaining muscle strength in lower limbs, but no difference was found in HGS. Accordingly, HGS also did not differ between regularly exercising and inactive women. However, Novak and Vute (2013) reported opposite results as they found significant difference in HGS between trained and untrained older women. It is reported that through the life span the age-associated decline of muscle quality in women is about 20% greater in lower limbs compared to upper limbs (Lynch et al., 1999), which could explain the difference in upper and lower limbs strength. According to the results of our study, regular physical exercising could be one of the factors to reduce the decline of muscle strength among older women.

Muscle quality describes combination of muscle functionality and muscle mass (Fragala et al., 2015), and is lately used for assessing physical capability in older adults (Fragala et al., 2015; Mankowski et al., 2015). In our study, lower limb muscle quality value was 30% higher in regularly exercising women compared to inactive older women. Upper limb muscle quality was 9% higher in regularly exercising women compared to inactive women, whereas this difference was not statistically significant, however clinical significance between the regularly exercising and inactive healthy older women was suggested. It is reported that long-term recreational PA has favorable outcome for muscle quality (Barbat-Artigas et al., 2014). Though there was no difference in ALM or

ALMI between regularly exercising and inactive women, we found that inactive women had lower values for RMM, which is associated with physical performance in older people (Bijlsma et al., 2014). Therefore, long-term physical exercising may reduce the loss of RMM and muscle quality, and thereby improve physical capability in older people.

The results from the present study demonstrate that regularly exercising women had significantly lower body mass and BMI. Zoico et al. (2010) reported that higher body mass and BMI were associated with higher liability to develop functional limitations. Our study results agree with those reported by Bocalini et al. (2009), who observed significant reduction in body mass, BMI and body fat% among older women as a result of 24-week strength training. However, age-related changes in body mass and body composition are influenced besides PA by nutritional intake (Thompson, 2002) and reduction in resting metabolic rate (St-Onge and Gallagher, 2010). In our study, FFM did not differ between regularly exercising and inactive women, but regularly exercising women FM was 27% lower compared to inactive women. Misisic et al. (2007) and Vilaça et al. (2014) associated higher whole-body FM with lower physical performance in older people. This finding supports the results of our study where inactive older women who had higher FM value also had lower muscle quality values and worse results in mobility parameters. Therefore, physical exercising could be one part of avoiding overweight and preventing accumulation of excess FM and therefore affect maintaining higher level of physical capacity in older women.

Regularly exercising women had significantly better results for mobility, they covered roughly 14% longer distance during the 6MWT and performed FTSTS test 17% faster compared to inactive women (Table 2). Novak and Vute (2013) highlighted the abilities that are essential for independent life: upper and lower limbs muscle strength, flexibility, balance and gait. Also, distance covered in 6MWT has been associated with the difficulty of performing everyday activities (Vilaça et al., 2014). Older adults who have mobility impairments have higher risk of mortality and loss of independence as compared to peers who do not have problems with mobility (Hirvensalo et al., 2000). This suggests that physical exercising may be one strategy to help maintain older people independence for everyday activities.

When examining the relationship between skeletal muscle mass, muscle function and mobility in healthy older women we found that LES and power output during CMJ adjusted with body mass, RFD of the leg extensor muscles and RMM had significant moderate correlations with 6MWT or TUG. Higher values for LES adjusted for body mass, RFD of leg extensor muscles and RMM signify for longer distance covered in 6MWT (Figure 1). Higher values for power output during CMJ for kg per body mass imply a faster performance in TUG (Figure 2). Therefore, older people could benefit from maintaining lower extremity strength and power output to prevent mobility impairments (Puthoff and Nielsen, 2007). As reported mobility is related to independence among older adults (Hirvensalo et al., 2000; Vilaça et al., 2014), higher values for

strength and power output lowers the risk of becoming dependent in older age. Our study results show that regularly exercising older women had higher values for lower extremity muscle strength and mobility compared to inactive women.

## **6.2 Associations of distinct levels of physical activity with mobility in healthy older women**

This study (Paper II) evaluated the differences in body composition and mobility variables in different groups of older women engaged to MVPA accumulated in bouts < 10 min and at least 10 min or more. In addition, the relationships between distinct levels of PA and mobility parameters were examined. The results demonstrated that MVPA in at least 10 min bouts might be more beneficial concerning better mobility among older women, compared to MVPA accumulated in < 10 min bouts. Moreover, MVPA was associated with mobility parameters, and was the strongest independent predictor for all mobility tests. It was found that MVPA, whether occurred in bouts lasting at least or < 10 min, was associated with better dynamic and static balance, lower limbs strength and aerobic endurance, which all characterize better mobility in older women. According to our findings, LPA did not have such associations with body composition nor mobility parameters, thus at least the intensity of MPA may appear to be beneficial regarding better mobility parameters in older women.

In our study, there were no significant differences between studied groups regarding body composition parameters; however, there was a tendency regarding higher BMI and FM in less physically active groups (Table 3). Higher FM is claimed to be one of the major factors aggravating physical disabilities among older adults (Vilaça et al., 2014) due to large amount of FM (St-Onge and Gallagher, 2010). According to Vilaça et al. (2014), greater quantity of FFM or LBM are not sufficient to maintain adequate physical function in obese older adults, referring to the negative effect of excess FM. In addition, higher whole-body FM has been associated with lower physical performance in older adults (Legrand et al., 2013). These findings support the results of our study where we found significant difference in mobility tests results, where women in L-MVPA group presented worse results for mobility tests compared to women in H-MVPA and M-MVPA groups. Incidentally, results for women in H-MVPA and M-MVPA groups were not different. This indicates that the accumulation of 10 min bouted MVPA (MVPA accumulating in > 10 min bouts) could be more favorable concerning lower FM and physical performance compared to a short bout MVPA (MVPA accumulating in < 10 min bouts), which leads to better coping with everyday activities in later life. These results are in line with the results reported by Yorston et al. (2012), who concluded that higher level of PA was associated with better physical function in older adults and higher level of PA progressively lowered likelihood of functional limitations. Hence, concerning MVPA accumulation, MVPA commitment in bouts of

at least 10 min could be more favorable for older women, regarding body composition and physical performance parameters in later life.

The associations between distinct levels of PA and mobility in older adults were also examined. We found that MPA and MVPA correlated with mobility parameters (Table 4; Figure 3), whereas no such relationship was observed with LPA. MVPA, regardless of bout duration, was positively correlated with distance covered during the 6MWT and negatively correlated with time spent performing TUG and FTSTS tests. Our results are in accordance with the conclusion made by Hupin et al. (2015), who found that engagement in MVPA even below recommended level reduced the mortality risk and risk decreases linearly with increases in PA engagement. It should be emphasized that LPA and even sedentary time were not related to mobility parameters in our study. LPA favorable impact for BMI has been found when engaged at least 300 min/week among older adults (Loprinzi et al., 2015). In our study, the average time spent in LPA was below 300 min/week, which may have had the reason that no differences were observed. This suggests that MVPA could have beneficial effect for better body composition and thereby to better mobility parameters even when engaged below recommended level. On the other hand, LPA was not associated with mobility parameters, at least quantities observed in the current study.

In addition, to stress the importance of PA in later life we adjusted aforementioned correlations with age and BMI, as age-related changes evolve progressively (Legrand et al., 2013) and BMI has proven to have significant impact on physical performance (Misic et al., 2007). After controlling for age and BMI, some relationships were lost, but despite this MVPA was still associated with TUG and 6MWT results. According to the results of our study, previous studies have demonstrated a positive impact of PA on physical performance among older adults (Bocalini et al., 2009; Bullo et al., 2015; Vilaça et al., 2014). These results suggest that the engagement in MVPA could be one of the important predictors of physical function in older women in later life.

Lean body mass indices were derived to assess the importance of PA on body composition and physical performance parameters. In our study, there were no differences in lean body mass indices between studied groups. RMM has been associated with physical performance among older adults (Bijlsma et al., 2014; Spira et al., 2015), which is in accordance with our results. Although significant difference in RMM between studied groups was not noted, more physically active women had better results for RMM. In addition, it has been found that muscle mass, independent of FM, cardiovascular and metabolic risk factors, is inversely associated with mortality risk in older adults (Srikanthan and Karlamangla, 2014). There were no differences in  $ALM_{BMI}$  and ALMI, which are considered as markers for sarcopenia (Bijlsma et al., 2014; Cruz-Jentoft et al., 2010), though more physically active women had better results compared to women in L-MVPA group. In addition, more physically active women also had higher ALM values compared to women in less physically active groups, although these differences were not significant. Similar results

for ALM indices may be due to the fact that all studied groups were more or less physically active and sedentary individuals were not involved in this study. Thus, MVPA may have favorable effect on sarcopenia indices, which are important cofounders in healthy aging.

Regression analysis demonstrated that MVPA time per day predicted TUG, FTSTS and 6MWT tests results, while other PA levels did not have independent effect on mobility parameters. These results may confirm the assumption that mobility among older women could be influenced by the level of MVPA in older women. Furthermore, sufficient MVPA could be one of the most important variables for older adults to maintain mobility parameters that are indispensable for maintaining independence in later life. This conclusion is in accordance with previous studies where the importance of MVPA has been emphasized as an important factor in maintaining older adult's independence (Foong et al., 2016; Lohne-Seiler et al., 2014).

### **6.3 Associations of inflammatory biomarkers with objectively measured physical activity in healthy older women**

This study (Paper III) examined the associations between blood biomarkers and PA indices in a group of healthy older women. According to our findings, serum resistin concentration was associated with steps per day. Moreover, steps per day was the strongest independent predictor for resistin concentration. Sedentary time and LPA were not associated with any measured blood biomarker concentrations among healthy older women.

In our study, the average daily steps count was higher compared to what has been reported before for similar population. In Tudor-Locke et al. (2013) study, the highest counts for steps per day per older age group was just below 7000 steps/day, in Gonzales et al. (2015), the mean steps per day was around 7200 steps/day and Jürimäe et al. (2010) 7700 steps/day. In our study, the average steps per day count was above 9000 steps, demonstrating that older females volunteered in our study were more physically active than participants in other similar studies. Age is inversely associated with steps per day, meaning older adults take less steps per day compared to younger adults (Tudor-Locke et al., 2013). In addition, it has also been stated that higher count of steps per day is associated with lower all-cause mortality risk (Yamamoto et al., 2018), consequently steps per day could be meaningful contributor for older adults regarding healthy aging. The recommended level of PA for older adults aged 65 and older is 150 min of MVPA per week, accumulated in at least 10 min bouts (WHO, 2011). The step-defined recommendation for older adults is 7100 steps/day and this is based on estimations that this amount of steps will include an accumulated 150 min of MVPA per week (Tudor-Locke et al., 2011). In our study, 68% of participants weekly mean daily steps count was more than 7100

steps/day. Accordingly, our subjects were relatively highly physically active older women.

One of the important findings of the present study was a significant negative association between steps per day and resistin. Resistin has been defined as a risk factor for atherosclerotic cardiovascular diseases (Reilly et al., 2005), and higher resistin levels have been associated with coronary heart disease and cardiovascular disease events in older adults (Gencer et al., 2016). In addition, resistin was the only blood biomarker examined in our study to have an independent predictor from PA indices. Steps per day explained 8.9% of the variance in serum resistin level in our group of physically active older women. In accordance, it has previously been reported that serum resistin concentration is inversely associated with PA (Marcelino-Rodríguez et al., 2017), also authors concluded that resistin is potentially useful biomarker of PA in efforts to improve health in general population (Marcelino-Rodríguez et al., 2017). These results suggest that PA, especially steps per day, could have meaningful association with resistin concentration in older women and higher count of steps per day may be associated with lower resistin concentration and through this lower the likelihood of cardiovascular disease events in healthy older women.

Serum levels of leptin have been shown to be associated with increased inflammation and morbidity (Mishra et al., 2015). On the other hand, it has been reported that moderately elevated concentration of serum leptin is independently associated with lower risk of all caused mortality and cardiovascular disease related mortality among older women (Mishra et al., 2015), but higher leptin concentration is associated with greater risk of frailty in older adults (Lana et al., 2017). In our study, leptin concentration was negatively associated with MVPA after controlling for age. To our knowledge, there are no studies conducted so far to investigate the relationship of objectively measured PA by accelerometers and leptin among healthy physically active older women. Although studies among different age groups and confounding factors diseases have reported controversial results as several studies have concluded that everyday PA may reduce leptin concentration whereas other have reported no change (Bouassida et al., 2006). Our results are in accordance with studies where leptin concentration has been shown to have inverse relationship with PA among healthy women (Alessa et al., 2017).

We demonstrated the tendency for lower concentrations of studied blood biomarkers among more physically active older women. This is in accordance with previously published data which show that higher levels of PA are associated with lower concentrations of inflammation markers among elderly (Colbert et al., 2004; Geffken et al., 2001; Wu et al., 2014). Therefore, PA may have a beneficial effect in lowering inflammatory markers and through this lower the likelihood of cardiovascular diseases. In addition, higher concentration of CRP has been associated with increased likelihood of cardiovascular diseases (Tracy et al., 1997). In our study, circulating CRP concentration was not associated with PA indices in older women. However, Colbert et al. (2004) found that inflammatory markers, including CRP, were lower in older adults



with higher levels of exercise and non-exercise activity. There are also multiple other studies stating similar finding (Monteiro-Junior et al., 2018). In addition, it has been found that TNF- $\alpha$  is one of the causative agents underlying bone loss induced by oestrogen deficiency in older females (Pacifici, 1996). The relationship between serum TNF- $\alpha$  and PA has remained controversial for older population (Monteiro-Junior et al., 2018). Colbert et al. (2004) found that TNF- $\alpha$  level was lower among older adults with higher engagement in physical exercise, however no relationship was observed between TNF- $\alpha$  concentration and non-exercise PA. Similarly, in our study, no associations between TNF- $\alpha$  concentration and objectively assessed PA indices were found among older women.

## 6.4 Limitations and strengths

There are some limitations in these studies. Primarily, the relatively small sample size of older women in Study I, which may not be representative of older women of this age. However, in accordance with our study, there is a number of studies with similar sample size (Goldberg et al., 2012; Pinto et al., 2014; Puthoff and Nielsen, 2007). Secondly, these are cross-sectional studies, which limits our ability to make causal inferences. In addition, we did not map all cofounders that could interfere with studied parameters, for example daily nutrition data or previous commitment to PA, therefore there could be some other factors influencing body composition and mobility parameters among studied older women. Furthermore, only women were recruited to current studies, therefore these results are not generalizable to overall older population. On the other hand, it has been found that women are 1.5 times as likely to experience functional limitation in all age groups (Yorston et al., 2012), which makes them more vulnerable regarding physical impairments compared to men.

Moreover, all data gathered concerning physical exercising were self-reported by the participants in Study I. When collating results from Studies I and II, subjects categorized in non-active group according to their self-reported PA history and type in Study I had similar results for some outcome variables compared to M-MVPA group in Study II. This may indicate that subjects in inactive group have underestimated or subjects in exercising group have overestimated their PA. This demonstrates that objectively assessed PA should have also been used to distinguish different PA groups in Study I similarly to Study II.

This study has also some strengths. Overall, our study samples were compiled of healthy older women without any mobility disorders, recruited from the community. Furthermore, objective assessment of PA and objective mobility tests to assess functional ability were used in Study II. Older women, in our study, were more physically active compared to usual commitment of PA in older age, which has not studied as thoughtfully before. To our best knowledge, there are no published studies where study sample average commitment to MVPA per day has been as high as 55 min, wherein in the most active group,

older women engaged to MVPA per day on average of 83 min. In comparison, in Johansson et al. (2015) study, older women committed in average of around 30 min of MVPA per day. In Lee et al. (2016) study with healthy older women, MVPA commitment per day was on average around 21 min and in Lohne-Seiler et al. (2014) and Foong et al. (2016) studies, the average MVPA time per day for older women was average of 28 min for corresponding age group. Accordingly, the main strengths of this study were objective research methods and a specific study sample, which has not been sufficiently studied so far.

## 7. CONCLUSIONS

1. Older women engaged to long-term PA had healthier body composition and better results for lower extremity muscle strength, muscle quality and mobility parameters compared to inactive healthy older women. Mobility in healthy older women was associated with lower extremity strength and power output of the leg extensor muscles and skeletal muscle mass per unit of body mass.
2. MVPA is associated with mobility variables among healthy older women. MVPA accumulated at least in 10 min bouts is more beneficial considering healthy body composition and mobility parameters among older women, while LPA had no associations to any measured mobility parameters.
3. Steps per day is inversely associated with resistin concentration among healthy older women. It appears that PA is associated with more favorable serum resistin concentration and through this may have reduced risk for multiple health conditions that are associated with chronic inflammation.

## 8. REFERENCES

1. Aagaard P, Magnusson PS, Larsson B, Kjær M, Krstrup P. Mechanical muscle function, morphology, and fiber type in lifelong trained elderly. *Medicine and Science in Sports and Exercise*. 2007;39(11):1989–96.
2. Abedi B, Karimi M, Mehranpour A, Sayyah M. Effects of eight-weeks of aerobic training on resistin levels and insulin resistance in sedentary middle-aged women. *Journal of Kermanshah University of Medical Science*. 2017;21(3):e69240.
3. Alessa HB, Chomistek AK, Hankinson SE, Barnett JB, Rood J, Matthews CE, Rimm EB, Willett WC, Hu FB, Tobias DK. Objective measures of physical activity and cardiometabolic and endocrine biomarkers. *Medicine and Science in Sports and Exercise*. 2017;49(9):1817–25.
4. Alissa EM, Alzughaihi LS, Marzouki ZM. Association between serum resistin, adiposity measures and inflammatory markers in women without cardiovascular diseases. *Chemistry and Physics of Lipids*. 2019;218:136–40.
5. Armijo-Olivo S, Warren S, Fuentes J, Magee DJ. Clinical relevance vs. statistical significance: using neck outcomes in patients with temporomandibular disorders as an example. *Manual Therapy*. 2011;16(6):563–72.
6. Bandeen-Roche K, Xue QL, Ferrucci L, Walston J, Guralnik JM, Chaves P, Zeger SL, Fried LP. Phenotype of frailty: characterization in the women's health and aging studies. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences*. 2006;61(3):262–6.
7. Barbat-Artigas S, Dupontgand S, Pion CH, Feiter-Murphy Y, Aubertin-Leheudre M. Identifying recreational physical activities associated with muscle quality in men and women aged 50 years and over. *Journal of Cachexia, Sarcopenia and Muscle*. 2014;5(3):221–8.
8. Barry E, Galvin R, Keogh C, Horgan F, Fahey T. Is the timed up and go test a useful predictor of risk of falls in community dwelling older adults: a systematic review and meta-analysis. *BMC Geriatrics*. 2014;14(1):14.
9. Baumgartner RN, Koehler KM, Gallagher D, Romero L, Heymsfield SB, Ross RR, Garry PJ, Lindeman RD. Epidemiology of sarcopenia among the elderly in New Mexico. *American Journal of Epidemiology*. 1998;147(8):755–63.
10. Bijlsma AY, Meskers CG, van den Eshof N, Westendorp RG, Sipilä S, Stenroth L, Sillanpää E, McPhee JS, Jones DA, Narici MV, Gapeyeva H, Pääsuke M, Voit T, Barnouin Y, Hogrel JY, Butler-Browne G, Maier AB. Diagnostic criteria for sarcopenia and physical performance. *Age*. 2014;36(1):275–85.
11. Binder EF, Yarasheski KE, Steger-May K, Sinacore DR, Brown M, Schechtman KB, Holloszy JO. Effects of progressive resistance training on body composition in frail older adults: results of a randomized, controlled trial. *Journals of Gerontology Series A: Biological Sciences and Medical Sciences*. 2005;60(11):1425–31.
12. Bischoff HA, Stähelin HB, Monsch AU, Iversen MD, Weyh A, Von Dechend M, Akos R, Conzelmann M, Dick W, Theiler R. Identifying a cut-off point for normal mobility: a comparison of the timed 'up and go' test in community-dwelling and institutionalised elderly women. *Age and Ageing*. 2003;32(3):315–20.
13. Bocalini DS, Serra AJ, dos Santos L, Murad N, Levy RF. Strength training preserves the bone mineral density of postmenopausal women without hormone replacement therapy. *Journal of Aging and Health*. 2009;21(3):519–27.
14. Bohannon RW, Shove ME, Barreca SR, Masters LM, Sigouin CS. Five-repetition sit-to-stand test performance by community-dwelling adults: A preliminary

- investigation of times, determinants, and relationship with self-reported physical performance. *Isokinetics and Exercise Science*. 2007;15(2):77–81.
15. Bohannon RW. Reference values for the five-repetition sit-to-stand test: a descriptive meta-analysis of data from elders. *Perceptual and Motor Skills*. 2006;103(1): 215–22.
  16. Botero JP, Shiguemoto GE, Prestes J, Marin CT, Do Prado WL, Pontes CS, Guerra RL, Ferreira FC, Baldissera V, Perez SE. Effects of long-term periodized resistance training on body composition, leptin, resistin and muscle strength in elderly postmenopausal women. *Journal of Sports Medicine and Physical Fitness*. 2013;53(3): 289–94.
  17. Bouassida A, Zalleg D, Bouassida S, Zaouali M, Feki Y, Zbidi A, Tabka Z. Leptin, its implication in physical exercise and training: a short review. *Journal of Sports Science and Medicine*. 2006;5(2):172–81.
  18. Brady AO, Straight CR, Schmidt MD, Evans EM. Impact of body mass index on the relationship between muscle quality and physical function in older women. *Journal of Nutrition, Health and Aging*. 2014;18(4):378–82.
  19. Bucci L, Yani SL, Fabbri C, Bijlsma AY, Maier AB, Meskers CG, Narici MV, Jones DA, McPhee JS, Seppet E, Gapeyeva H, Pääsuke M, Sipilä S, Kovanen V, Stenroth L, Musarò A, Hogrel JY, Barnouin Y, Butler-Browne G, Capri M, Franceschi C, Salvioli S. Circulating levels of adipokines and IGF-1 are associated with skeletal muscle strength of young and old healthy subjects. *Biogerontology*. 2013;14(3):261–72.
  20. Bullo V, Bergamin M, Gobbo S, Sieverdes JC, Zaccaria M, Neunhaeuserer D, Ermolao A. The effects of Pilates exercise training on physical fitness and wellbeing in the elderly: a systematic review for future exercise prescription. *Preventive Medicine*. 2015;75:1–11.
  21. Cawthon PM, Peters KW, Shardell MD, McLean RR, Dam TT, Kenny AM, Fragala MS, Harris TB, Kiel DP, Guralnik JM, Ferrucci L, Kritchevsky SB, Vassileva MT, Studenski SA, Alley DE. Cutpoints for low appendicular lean mass that identify older adults with clinically significant weakness. *Journals of Gerontology Series A: Biomedical Sciences and Medical Sciences*. 2014;69(5):567–75.
  22. Chien MY, Wu YT, Hsu AT, Yang RS, Lai JS. Efficacy of a 24-week aerobic exercise program for osteopenic postmenopausal women. *Calcified Tissue International*. 2000;67(6):443–8.
  23. Chodzko-Zajko WJ, Proctor DN, Fiatarone Singh MA, Minson CT, Nigg CR, Salem GJ, Skinner JS. Exercise and physical activity for older adults. *Medicine and Science in Sports and Exercise*. 2009;41(7):1510–30.
  24. Clark BC, Manini TM. What is dynapenia? *Nutrition*. 2012;28(5):495–503.
  25. Colbert LH, Visser M, Simonsick EM, Tracy RP, Newman AB, Kritchevsky SB, Pahor M, Taaffe DR, Brach J, Rubin S, Harris TB. Physical activity, exercise, and inflammatory markers in older adults: findings from the Health, Aging and Body Composition Study. *Journal of the American Geriatrics Society*. 2004;52(7):1098–104.
  26. Crane JD, MacNeil LG, Tarnopolsky MA. Long-term aerobic exercise is associated with greater muscle strength throughout the life span. *Journals of Gerontology Series A: Biomedical Sciences and Medical Sciences*. 2012;68(6):631–8.
  27. Cruz-Jentoft AJ, Baeyens JP, Bauer JM, Boirie Y, Cederholm T, Landi F, Martin FC, Michel JP, Rolland Y, Schneider SM, Topinková E, Vandewoude M, Zamboni

- M. Sarcopenia: European consensus on definition and diagnosis. *Age and Ageing*. 2010;39(4):412–23.
28. Daly RM, Ahlborg HG, Ringsberg K, Gardsell P, Sernbo I, Karlsson MK. Association between changes in habitual physical activity and changes in bone density, muscle strength, and functional performance in elderly men and women. *Journal of the American Geriatrics Society*. 2008;56(12):2252–60.
  29. Distefano G, Standley RA, Zhang X, Carnero EA, Yi F, Cornnell HH, Coen PM. Physical activity unveils the relationship between mitochondrial energetics, muscle quality, and physical function in older adults. *Journal of Cachexia, Sarcopenia and Muscle*. 2018;9(2):279–94.
  30. Doheny EP, Fan CW, Foran T, Greene BR, Cunningham C, Kenny RA. An instrumented sit-to-stand test used to examine differences between older fallers and non-fallers. *Engineering in Medicine and Biology Society*. 2011;2011:3063–6.
  31. Dohrn IM, Hagströmer M, Hellenius ML, Ståhle A. Gait speed, quality of life, and sedentary time are associated with steps per day in community-dwelling older adults with osteoporosis. *Journal of Aging and Physical Activity*. 2016;24(1):22–31.
  32. Englund U, Littbrand H, Sondell A, Pettersson U, Bucht G. A 1-year combined weight-bearing training program is beneficial for bone mineral density and neuromuscular function in older women. *Osteoporosis International*. 2005;16(9): 1117–23.
  33. Fielding RA, Guralnik JM, King AC, Pahor M, McDermott MM, Tudor-Locke C, Manini TM, Glynn NW, Marsh AP, Axtell RS, Hsu FC, Rejeski WJ. Dose of physical activity, physical functioning and disability risk in mobility-limited older adults: Results from the LIFE study randomized trial. *PloS One*. 2017;12(8): e0182155.
  34. Foong YC, Chherawala N, Aitken D, Scott D, Winzenberg T, Jones G. Accelerometer-determined physical activity, muscle mass, and leg strength in community-dwelling older adults. *Journal of Cachexia, Sarcopenia and Muscle*. 2016;7(3):275–83.
  35. Fragala MS, Kenny AM, Kuchel GA. Muscle quality in aging: a multi-dimensional approach to muscle functioning with applications for treatment. *Sports Medicine*. 2015;45(5):641–58.
  36. Francis P, Lyons M, Piasecki M, McPhee J, Hind K, Jakeman P. Measurement of muscle health in aging. *Biogerontology*. 2017;18(6):901–911.
  37. Freedson PS, Melanson E, Sirard J. Calibration of the computer science and applications, Inc. accelerometer. *Medicine and Science in Sports and Exercise*. 1998; 30(5):777–81.
  38. Freiburger E, Menz HB, Abu-Omar K, Rütten A. Preventing falls in physically active community-dwelling older people: a comparison of two intervention techniques. *Gerontology*. 2007;53(5):298–305.
  39. Fried LP, Tangen CM, Walston J, Newman AB, Hirsch C, Gottdiener J, Seeman T, Tracy R, Kop WJ, Burke G, McBurnie MA. Frailty in older adults: evidence for a phenotype. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences*. 2001;56(3):M146–56.
  40. Gale CR, Martyn CN, Cooper C, Sayer AA. Grip strength, body composition, and mortality. *International Journal of Epidemiology*. 2006;36(1):228–35.
  41. Gardner MM, Robertson MC, Campbell AJ. Exercise in preventing falls and fall related injuries in older people: a review of randomised controlled trials. *British Journal of Sports Medicine*. 2000;34(1):7–17.

42. Geffken DF, Cushman M, Burke GL, Polak JF, Sakkinen PA, Tracy RP. Association between physical activity and markers of inflammation in a healthy elderly population. *American Journal of Epidemiology*. 2001;153(3):242–50.
43. Gencer B, Auer R, De Rekeneire N, Butler J, Kalogeropoulos A, Bauer DC, Kritchevsky SB, Miljkovic I, Vittinghoff E, Harris T, Rodondi N. Association between resistin levels and cardiovascular disease events in older adults: the health, aging and body composition study. *Atherosclerosis*. 2016;245:181–6.
44. Gennuso KP, Gangnon RE, Matthews CE, Thraen-Borowski KM, Colbert LH. Sedentary behavior, physical activity, and markers of health in older adults. *Medicine and Science in Sports and Exercise*. 2013;45(8):1493–500.
45. Giannopoulou I, Fernhall B, Carhart R, Weinstock RS, Baynard T, Figueroa A, Kanaley JA. Effects of diet and/or exercise on the adipocytokine and inflammatory cytokine levels of postmenopausal women with type 2 diabetes. *Metabolism*. 2005;54(7):866–75.
46. Gianoudis J, Bailey CA, Daly RM. Associations between sedentary behaviour and body composition, muscle function and sarcopenia in community-dwelling older adults. *Osteoporosis International*. 2015;26(2):571–9.
47. Going SB, Williams DP, Lohman TG, Hewitt MJ. Aging, body composition, and physical activity: a review. *Journal of Aging and Physical Activity*. 1994;2(1):38–66.
48. Goldberg A, Chavis M, Watkins J, Wilson T. The five-times-sit-to-stand test: validity, reliability and detectable change in older females. *Aging Clinical and Experimental Research*. 2012;24(4):339–44.
49. Gonzales JU, Shephard J, Dubey N. Steps per day, daily peak stepping cadence, and walking performance in older adults. *Journal of Aging and Physical Activity*. 2015;23(3):395–400.
50. Goodpaster BH, Park SW, Harris TB, Kritchevsky SB, Nevitt M, Schwartz AV, Simonsick EM, Tylavsky FA, Visser M, Newman AB. The loss of skeletal muscle strength, mass, and quality in older adults: the health, aging and body composition study. *Journals of Gerontology Series A: Biological Sciences and Medical Sciences*. 2006;61(10):1059–64.
51. Gorman E, Hanson HM, Yang PH, Khan KM, Liu-Ambrose T, Ashe MC. Accelerometry analysis of physical activity and sedentary behavior in older adults: a systematic review and data analysis. *European Review of Aging and Physical Activity*. 2014;11:35–49.
52. Guadagnin EC, Da Rocha ES, Mota CB, Carpes FP. Effects of regular exercise and dual tasking on spatial and temporal parameters of obstacle negotiation in elderly women. *Gait and Posture*. 2015;42(3):251–6.
53. Guo SS, Zeller C, Chumlea WC, Siervogel RM. Aging, body composition, and lifestyle: the Fels Longitudinal Study. *The American Journal of Clinical Nutrition*. 1999;70(3):405–11.
54. Hansen BH, Kolle E, Dyrstad SM, Holme I, Anderssen SA. Accelerometer-determined physical activity in adults and older people. *Medicine and Science in Sports and Exercise*. 2012;44(2):266–72.
55. Harridge S, Magnusson G, Saltin B. Life-long endurance-trained elderly men have high aerobic power, but have similar muscle strength to non-active elderly men. *Aging Clinical and Experimental Research*. 1997;9(1–2):80–7.

56. Heesch KC, Byles JE, Brown WJ. Prospective association between physical activity and falls in community-dwelling older women. *Journal of Epidemiology and Community Health*. 2008;62(5):421–6.
57. Higuera-Fresnillo S, Guallar-Castillón P, Cabanas-Sanchez V, Banegas JR, Rodríguez-Artalejo F, Martínez-Gómez D. Changes in physical activity and cardiovascular mortality in older adults. *Journal of Geriatric Cardiology*. 2017;14(4):280–1.
58. Hirvensalo M, Rantanen T, Heikkinen E. Mobility difficulties and physical activity as predictors of mortality and loss of independence in the community-living older population. *Journal of the American Geriatrics Society*. 2000;48(5):493–8.
59. Hupin D, Roche F, Gremeaux V, Chatard JC, Oriol M, Gaspoz JM, Barthélémy JC, Edouard P. Even a low-dose of moderate-to-vigorous physical activity reduces mortality by 22% in adults aged  $\geq 60$  years: a systematic review and meta-analysis. *British Journal of Sports Medicine*. 2015;49(19):1262–7.
60. Janssen I, Heymsfield SB, Ross R. Low relative skeletal muscle mass (sarcopenia) in older persons is associated with functional impairment and physical disability. *Journal of the American Geriatrics Society*. 2002;50(5):889–96.
61. Jefferis BJ, Parsons TJ, Sartini C, Ash S, Lennon LT, Wannamethee SG, Lee IM, Whincup PH. Does duration of physical activity bouts matter for adiposity and metabolic syndrome? A cross-sectional study of older British men. *International Journal of Behavioral Nutrition and Physical Activity*. 2016;13(1):36.
62. Johansson J, Nordström A, Nordström P. Objectively measured physical activity is associated with parameters of bone in 70-year-old men and women. *Bone*. 2015; 81:72–9.
63. Jones TE, Basilio JL, Brophy PM, McCammon MR, Hickner RC. Long-term exercise training in overweight adolescents improves plasma peptide YY and resistin. *Obesity*. 2009;17(6):1189–95.
64. Jürimäe J, Kums T, Jürimäe T. Plasma adiponectin concentration is associated with the average accelerometer daily steps counts in healthy elderly females. *European Journal of Applied Physiology*. 2010;109(5):823–8.
65. Kallman DA, Plato CC, Tobin JD. The role of muscle loss in the age-related decline of grip strength: cross-sectional and longitudinal perspectives. *Journal of Gerontology*. 1990;45(3):M82–8.
66. Kemmler W, von Stengel S. Exercise frequency, health risk factors, and diseases of the elderly. *Archives of Physical Medicine and Rehabilitation*. 2013;94(11):2046–53.
67. Kennedy BK, Berger SL, Brunet A, Campisi J, Cuervo AM, Epel ES, Franceschi C, Lithgow GJ, Morimoto RI, Pessin JE, Rando TA, Richardson A, Schadt EE, Wyss-Coray T, Sierra F. Aging: a common driver of chronic diseases and a target for novel interventions. *Cell*. 2014;159(4):709–713.
68. Lachman S, Boekholdt SM, Luben RN, Sharp SJ, Brage S, Khaw KT, Peters RJ, Wareham NJ. Impact of physical activity on the risk of cardiovascular disease in middle-aged and older adults: EPIC Norfolk prospective population study. *European Journal of Preventive Cardiology*. 2018;25(2):200–8.
69. Lana A, Valdés-Bécares A, Buño A, Rodríguez-Artalejo F, Lopez-García E. Serum leptin concentration is associated with incident frailty in older adults. *Aging and Disease*. 2017;8(2):240–249.
70. Laukkanen P, Heikkinen E, Kauppinen M. Muscle strength and mobility as predictors of survival in 75–84-year-old people. *Age and Ageing*. 1995;24:468–73



71. Lee I, Ha C, Kang H. Association of sarcopenia and physical activity with femur bone mineral density in elderly women. *Journal of Exercise Nutrition and Biochemistry*. 2016;20(1):23–8.
72. Legrand D, Adriaensen W, Vaes B, Matheï C, Wallemacq P, Degryse J. The relationship between grip strength and muscle mass (MM), inflammatory biomarkers and physical performance in community-dwelling very old persons. *Archives of Gerontology and Geriatrics*. 2013;57(3):345–51.
73. Lohne-Seiler H, Hansen BH, Kolle E, Anderssen SA. Accelerometer-determined physical activity and self-reported health in a population of older adults (65–85 years): a cross-sectional study. *BMC Public Health*. 2014;14(1):284.
74. López-Otín C, Blasco MA, Partridge L, Serrano M, Kroemer G. The hallmarks of aging. *Cell*. 2013;153(6):1194–217.
75. Loprinzi PD, Lee H, Cardinal BJ. Evidence to support including lifestyle light-intensity recommendations in physical activity guidelines for older adults. *American Journal of Health Promotion*. 2015;29(5):277–84.
76. Lord SR, Murray SM, Chapman K, Munro B, Tiedemann A. Sit-to-stand performance depends on sensation, speed, balance, and psychological status in addition to strength in older people. *Journals of Gerontology Series A: Biological Sciences and Medical Sciences*. 2002;57(8):M539–43.
77. Lou J, Huang L, Wang A, Liu Y, Cai R, Li W, Zhou MS. Resistin-induced endoplasmic reticulum stress contributes to the impairment of insulin signaling in endothelium. *Frontiers in Pharmacology*. 2018;9:1226.
78. Lynch NA, Metter EJ, Lindle RS, Fozard JL, Tobin JD, Roy TA, Fleg JL, Hurley BF. Muscle quality. I. Age-associated differences between arm and leg muscle groups. *Journal of Applied Physiology*. 1999;86(1):188–94.
79. Maden-Wilkinson TM, McPhee JS, Jones DA, Degens H. Age-related loss of muscle mass, strength, and power and their association with mobility in recreationally-active older adults in the United Kingdom. *Journal of Aging and Physical Activity*. 2015; 23(3):352–60.
80. Makizako H, Shimada H, Doi T, Tsutsumimoto K, Nakakubo S, Hotta R, Suzuki T. Predictive cutoff values of the Five-Times Sit-to-Stand Test and the Timed “Up & Go” Test for disability incidence in older people dwelling in the community. *Physical Therapy*. 2017;97(4):417–24.
81. Maltais ML, Desroches J, Dionne IJ. Changes in muscle mass and strength after menopause. *Journal of Musculoskeletal and Neuronal Interactions*. 2009;9(4):186–97.
82. Mankowski RT, Anton SD, Aubertin-Leheudre M. The role of muscle mass, muscle quality, and body composition in risk for the metabolic syndrome and functional decline in older adults. *Current Geriatrics Reports*. 2015;4(3):221–8.
83. Marcelino-Rodríguez I, Gonzalez DA, Alemán-Sánchez JJ, Díaz BB, Pérez MD, Gannar F, Coello SD, Fernández FJ, de León AC. Inverse association of resistin with physical activity in the general population. *PloS One*. 2017;12(8):e0182493.
84. Mattioli RÁ, Cavalli AS, Ribeiro JA, Silva MC. Association between handgrip strength and physical activity in hypertensive elderly individuals. *Revista Brasileira de Geriatria e Gerontologia*. 2015;18(4):881–91.
85. McPhee JS, French DP, Jackson D, Nazroo J, Pendleton N, Degens H. Physical activity in older age: perspectives for healthy ageing and frailty. *Biogerontology*. 2016;17(3):567–80.

86. McPhee JS, Hogrel JY, Maier AB, Seppet E, Seynnes OR, Sipilä S, Bottinelli R, Barnouin Y, Bijlsma AY, Gapeyeva H, Maden-Wilkinson TM, Meskers CG, Pääsuke M, Sillanpää E, Stenroth L, Butler-Browne G, Narici MV, Jones DA. Physiological and functional evaluation of healthy young and older men and women: design of the European MyoAge study. *Biogerontology*. 2013;14(3):325–37.
87. Metter EJ, Talbot LA, Schrager M, Conwit R. Skeletal muscle strength as a predictor of all-cause mortality in healthy men. *Journals of Gerontology Series A: Biological Sciences and Medical Sciences*. 2002;57(10):B359–65.
88. Milanović Z, Pantelić S, Trajković N, Sporiš G, Kostić R, James N. Age-related decrease in physical activity and functional fitness among elderly men and women. *Clinical Interventions in Aging*. 2013;8:549–56.
89. Mishra S, Harris TB, Hsueh WC, Hue T, Leak TS, Li R, Mehta M, Vaisse C, Sahyoun NR. The association of serum leptin with mortality in older adults. *PLoS One*. 2015;10(10):e0140763.
90. Misic MM, Rosengren KS, Woods JA, Evans EM. Muscle quality, aerobic fitness and fat mass predict lower-extremity physical function in community-dwelling older adults. *Gerontology*. 2007;53(5):260–6.
91. Monteiro AM, Silva P, Forte P, Carvalho J. The effects of daily physical activity on functional fitness, isokinetic strength and body composition in elderly community-dwelling women. *Journal of Human Sport and Exercise*. 2019;14(2):385–98.
92. Monteiro-Junior RS, de Tarso Maciel-Pinheiro P, da Matta Mello Portugal E, da Silva Figueiredo LF, Terra R, Carneiro LS, Rodrigues VD, Nascimento OJ, Deslandes AC, Laks J. Effect of exercise on inflammatory profile of older persons: systematic review and meta-analyses. *Journal of Physical Activity and Health*. 2018;15(1):64–71.
93. Muir JM, Ye C, Bhandari M, Adachi JD, Thabane L. The effect of regular physical activity on bone mineral density in post-menopausal women aged 75 and over: a retrospective analysis from the Canadian multicentre osteoporosis study. *BMC Musculoskeletal Disorders*. 2013;14(1):253.
94. Nakamura Y, Tanaka K, Yabushita N, Sakai T, Shigematsu R. Effects of exercise frequency on functional fitness in older adult women. *Archives of Gerontology and Geriatrics*. 2007;44(2):163–73.
95. Nascimento Dda C, Tibana RA, Benik FM, Fontana KE, Ribeiro Neto F, Santana FS, Santos-Neto L, Silva RA, Silva AO, Farias DL, Balsamo S, Prestes J. Sustained effect of resistance training on blood pressure and hand grip strength following a detraining period in elderly hypertensive women: a pilot study. *Journal of Clinical Interventions in Aging*. 2014;9:219–25.
96. Newman AB, Kupelian V, Visser M, Simonsick EM, Goodpaster BH, Kritchevsky SB, Tyllavsky FA, Rubin SM, Harris TB. Strength, but not muscle mass, is associated with mortality in the health, aging and body composition study cohort. *Journals of Gerontology Series A: Biological Sciences and Medical Sciences*. 2006;61(1):72–7.
97. Ng SS, Cheung SY, Lai LS, Liu AS, Ieong SH, Fong SS. Five times sit-to-stand test completion times among older women: influence of seat height and arm position. *Journal of Rehabilitation Medicine*. 2015;47(3):262–6.
98. Novak T, Vute R. Long-term effects of regular exercising in elderly women. *Annales Kinesiologiae*. 2013;4(2):109–127.

99. O'Sullivan M, Blake C, Cunningham C, Boyle G, Finucane C. Correlation of accelerometry with clinical balance tests in older fallers and non-fallers. *Age and Ageing*. 2009;38(3):308–13.
100. Pääsuke M, Ereline J, Gapeyeva H. Age-related differences in knee extension rate of isometric force development and vertical jumping performance in women. *Journal of Sports Medicine and Physical Fitness*. 2003;43(4):453–8.
101. Pacifici R. Estrogen, cytokines, and pathogenesis of postmenopausal osteoporosis. *Journal of Bone and Mineral Research*. 1996;11(8):1043–51.
102. Patel KV, Coppin AK, Manini TM, Lauretani F, Bandinelli S, Ferrucci L, Guralnik JM. Midlife physical activity and mobility in older age: The InCHIANTI study. *American Journal of Preventive Medicine*. 2006;31(3):217–24.
103. Paterson DH, Warburton DE. Physical activity and functional limitations in older adults: a systematic review related to Canada's Physical Activity Guidelines. *International Journal of Behavioral Nutrition and Physical Activity*. 2010;7(1):38.
104. Pinto RS, Correa CS, Radaelli R, Cadore EL, Brown LE, Bottaro M. Short-term strength training improves muscle quality and functional capacity of elderly women. *Age*. 2014;36(1):365–72.
105. Pisciotto MV, Pinto SS, Szejnfeld VL, Castro CH. The relationship between lean mass, muscle strength and physical ability in independent healthy elderly women from the community. *Journal of Nutrition, Health and Aging*. 2014; 18(5): 554–8.
106. Power GA, Dalton BH, Behm DG, Doherty TJ, Vandervoort AA, Rice CL. Motor unit survival in lifelong runners is muscle dependent. *Medicine and Science in Sports and Exercise*. 2012;44(7):1235–42.
107. Prestes J, Shiguemoto G, Botero JP, Frollini A, Dias R, Leite R, Pereira G, Magosso R, Baldissera V, Cavaglieri C, Perez S. Effects of resistance training on resistin, leptin, cytokines, and muscle force in elderly post-menopausal women. *Journal of Sports Sciences*. 2009;27(14):1607–15.
108. Puthoff ML, Nielsen DH. Relationships among impairments in lower-extremity strength and power, functional limitations, and disability in older adults. *Physical Therapy*. 2007;87(10):1334–47.
109. Qatanani M, Szwergold NR, Greaves DR, Ahima RS, Lazar MA. Macrophage-derived human resistin exacerbates adipose tissue inflammation and insulin resistance in mice. *Journal of Clinical Investigation*. 2009;119(3):531–9.
110. Radaelli R, Botton CE, Wilhelm EN, Bottaro M, Lacerda F, Gaya A, Moraes K, Peruzzolo A, Brown LE, Pinto RS. Low-and high-volume strength training induces similar neuromuscular improvements in muscle quality in elderly women. *Experimental Gerontology*. 2013;48(8):710–6.
111. Rantanen T. Promoting mobility in older people. *Journal of Preventive Medicine and Public Health*. 2013;46:S50–54.
112. Reilly MP, Lehrke M, Wolfe ML, Rohatgi A, Lazar MA, Rader DJ. Resistin is an inflammatory marker of atherosclerosis in humans. *Circulation*. 2005;111(7):932–9.
113. Rowe JW, Kahn RL. Successful aging. *Gerontologist*. 1997;37(4):433–40.
114. Sallam N, Laher I. Exercise modulates oxidative stress and inflammation in aging and cardiovascular diseases. *Oxidative Medicine and Cellular Longevity*. 2016; 2016:7239639
115. Santilli V, Bernetti A, Mangone M, Paoloni M. Clinical definition of sarcopenia. *Clinical Cases in Mineral and Bone Metabolism*. 2014;11(3):177.

116. Santos L, Ribeiro AS, Schoenfeld BJ, Nascimento MA, Tomeleri CM, Souza MF, Pina FL, Cyrino ES. The improvement in walking speed induced by resistance training is associated with increased muscular strength but not skeletal muscle mass in older women. *European Journal of Sport Science*. 2017;17(4):488–94.
117. Schaap LA, Pluijm SM, Deeg DJ, Visser M. Inflammatory markers and loss of muscle mass (sarcopenia) and strength. *American Journal of Medicine*. 2006; 119(6):526.e9–17.
118. Sillanpää E, Stenroth L, Bijlsma AY, Rantanen T, McPhee JS, Maden-Wilkinson TM, Jones DA, Narici MV, Gapeyeva H, Pääsuke M, Barnouin Y, Hogrel JY, Butler-Browne GS, Meskers CG, Maier AB, Törmäkangas T, Sipilä S. Associations between muscle strength, spirometric pulmonary function and mobility in healthy older adults. *Age*. 2014;36(4):9667.
119. Singh T, Newman AB. Inflammatory markers in population studies of aging. *Ageing Research Reviews*. 2011;10(3):319–29.
120. Spira D, Buchmann N, Nikolov J, Demuth I, Steinhagen-Thiessen E, Eckardt R, Norman K. Association of low lean mass with frailty and physical performance: a comparison between two operational definitions of sarcopenia—data from the Berlin Aging Study II (BASE-II). *Journals of Gerontology Series A: Biomedical Sciences and Medical Sciences*. 2015;70(6):779–84.
121. Srikanthan P, Karlamangla AS. Muscle mass index as a predictor of longevity in older adults. *American Journal of Medicine*. 2014;127(6):547–53.
122. Srivastava S. The mitochondrial basis of aging and age-related disorders. *Genes*. 2017;8(12):398.
123. Steele J, Raubold K, Kemmler W, Fisher J, Gentil P, Giessing J. The effects of 6 months of progressive high effort resistance training methods upon strength, body composition, function, and wellbeing of elderly adults. *BioMed Research International*. 2017;2017:2541090.
124. Stensvold D, Viken H, Rognum Ø, Skogvoll E, Steinshamn S, Vatten LJ, Coombes JS, Anderssen SA, Magnussen J, Ingebrigtsen JE, Fiatarone Singh MA, Langhammer A, Støylen A, Helbostad JL, Wisløff U. A randomised controlled study of the long-term effects of exercise training on mortality in elderly people: study protocol for the Generation 100 study. *BMJ Open*. 2015;5(2):e007519.
125. St-Onge MP, Gallagher D. Body composition changes with aging: the cause or the result of alterations in metabolic rate and macronutrient oxidation? *Nutrition*. 2010;26(2):152–5.
126. Strasser B, Keinrad M, Haber P, Schobersberger W. Efficacy of systematic endurance and resistance training on muscle strength and endurance performance in elderly adults—a randomized controlled trial. *Wiener Klinische Wochenschrift*. 2009;121(23–24):757–64.
127. Suragani M, Aadinarayana VD, Pinjari AB, Tanneeru K, Guruprasad L, Banerjee S, Pandey S, Chaudhuri TK, Ehtesham NZ. Human resistin, a proinflammatory cytokine, shows chaperone-like activity. *Proceedings of the National Academy of Sciences*. 2013;110(51):20467–72.
128. Thompson LV. Skeletal muscle adaptations with age, inactivity, and therapeutic exercise. *Journal of Orthopaedic and Sports Physical Therapy*. 2002;32(2):44–57.
129. Toth MJ, Tchernof A, Sites CK, Poehlman ET. Menopause-related changes in body fat distribution. *Annals of the New York Academy of Sciences*. 2000;904(1): 502–6.
130. Tracy RP, Lemaitre RN, Psaty BM, Ives DG, Evans RW, Cushman M, Meilahn EN, Kuller LH. Relationship of C-reactive protein to risk of cardiovascular disease

- in the elderly: results from the Cardiovascular Health Study and the Rural Health Promotion Project. *Arteriosclerosis, Thrombosis, and Vascular Biology*. 1997; 17(6):1121–7.
131. Tudor-Locke C, Craig CL, Aoyagi Y, Bell RC, Croteau KA, De Bourdeaudhuij I, Ewald B, Gardner AW, Hatano Y, Lutes LD, Matsudo SM, Ramirez-Marrero FA, Rogers LQ, Rowe DA, Schmidt MD, Tully MA, Blair SN. How many steps/day are enough? For older adults and special populations. *International Journal of Behavioral Nutrition and Physical Activity*. 2011;8(1):80.
  132. Tudor-Locke C, Schuna Jr JM, Barreira TV, Mire EF, Broyles ST, Katzmarzyk PT, Johnson WD. Normative steps/day values for older adults: NHANES 2005–2006. *Journals of Gerontology Series A: Biomedical Sciences and Medical Sciences*. 2013;68(11):1426–32.
  133. Vahtrik D, Ereline J, Gapeyeva H, Pääsuke M. Postural stability in relation to anthropometric and functional characteristics in women with knee osteoarthritis following total knee arthroplasty. *Archives of Orthopaedic and Trauma Surgery*. 2014;134(5):685–92.
  134. Vilaça KH, Carneiro JA, Ferriolli E, da Costa Lima NK, de Paula FJ, Moriguti JC. Body composition, physical performance and muscle quality of active elderly women. *Archives of Gerontology and Geriatrics*. 2014;59(1):44–8.
  135. Visser M, Simonsick EM, Colbert LH, Brach J, Rubin SM, Kritchevsky SB, Newman AB, Harris TB, Health ABC Study. Type and intensity of activity and risk of mobility limitation: the mediating role of muscle parameters. *Journal of the American Geriatrics Society*. 2005;53(5):762–70.
  136. World Health Organization (2011) Global recommendations on physical activity for health. World Health Organization, Geneva.
  137. Wu SH, Shu XO, Chow WH, Xiang YB, Zhang X, Li HL, Cai Q, Milne G, Ji BT, Cai H, Rothman N, Gao YT, Zheng W, Yang G. Nonexercise physical activity and inflammatory and oxidative stress markers in women. *Journal of Women's Health*. 2014;23(2):159–67.
  138. Yamamoto N, Miyazaki H, Shimada M, Nakagawa N, Sawada SS, Nishimuta M, Kimura Y, Kawakami R, Nagayama H, Asai H, Lee IM, Blair SN, Yoshitake Y. Daily step count and all-cause mortality in a sample of Japanese elderly people: a cohort study. *BMC Public Health*. 2018;18(1):540.
  139. Yazdanyar A, Aziz MM, Enright PL, Edmundowicz D, Boudreau R, Sutton-Tyrell K, Kuller L, Newman AB. Association between 6-minute walk test and all-cause mortality, coronary heart disease-specific mortality, and incident coronary heart disease. *Journal of Aging and Health*. 2014;26(4):583–99.
  140. Yorston LC, Kolt GS, Rosenkranz RR. Physical activity and physical function in older adults: the 45 and up study. *Journal of the American Geriatrics Society*. 2012;60(4):719–25.
  141. Zhang F, Ferrucci L, Culham E, Metter EJ, Guralnik J, Deshpande N. Performance on five times sit-to-stand task as a predictor of subsequent falls and disability in older persons. *Journal of Aging and Health*. 2013;25(3):478–92.
  142. Zoico E, Rossi A, Di Francesco V, Sepe A, Oliosio D, Pizzini F, Fantin F, Bosello O, Cominacini L, Harris TB, Zamboni M. Adipose tissue infiltration in skeletal muscle of healthy elderly men: relationships with body composition, insulin resistance, and inflammation at the systemic and tissue level. *Journals of Gerontology Series A: Biomedical Sciences and Medical Sciences*. 2010;65(3):295–9.

## SUMMARY IN ESTONIAN

### **Kehalise aktiivsuse seosed keha koostise, mobiilsuse ja vere biokeemiliste näitajatega tervetel vanemaealistel naistel**

#### **Sissejuhatus**

Vananemisega kaasnevad mitmed muutused närvi-lihassüsteemis, luukoes, keha koostises ning motoorses võimekuses. Väheneb lihasmass ja -jõud, suureneb rasvamassi osakaal, väheneb luumass ning suureneb tõenäosus haigestuda erinevatesse kroonilistesse haigustesse. Lisaks vananemisele võib neid muutusi seostada ka kehalise aktiivsusega, mis väheneb koos vanuse suurenemisega. Kõige selle tulemusena väheneb vanemaealiste võimekuse iseseisvaks toimetulekuks igapäevastes tegevustes. Ehkki ei ole võimalik vältida vananemist ning ära hoida vananemisega kaasnevaid negatiivseid ilminguid võib kehalisel aktiivsusel olla positiivne mõju vananemisega seotud bioloogilistele protsessidele ning seeläbi vähendada inaktiivse eluviisi negatiivseid ilminguid hilisemas elus.

Edukas vananemine on defineeritud läbi kolme peamise komponendi: haiguste ja vigastuste vältimine, kõrge kognitiivne ja kehalise võimekuse säilitamine ning aktiivne osalemine sotsiaalsetes tegevustes. Varasemad uuringud on näidanud, et kehaliselt aktiivne elustiil ja väiksem tõenäosus iseseisvuse kaotamiseks vananedes on omavahel seotud. Lisaks on uuringud näidanud, et kehaline aktiivsus võib aeglustada ja/või edasi lükata vananemisega kaasnevaid negatiivseid ilminguid ja seeläbi vähendada riski iseseisvuse kaotamiseks vanemas eas. Kehaliselt mitte aktiivsetel vanemaealistel on kaks korda suurem risk iseseisvuse kaotamiseks vanemas eas võrreldes kehaliselt aktiivsete eakaaslastega, lisaks on kehalist aktiivsust seostatud väiksema riskiga haigestuda kroonilistesse haigustesse. Samas ei ole üheselt selge, millise intensiivsusega ja kestusega kehaline aktiivsus võiks olla piisav, et säilitada vanemaealiste kehaline võimekus ja seeläbi iseseisvus vanemas eas.

#### **Uurimustöö eesmärk ja ülesanded**

Uurimustöö eesmärgiks oli välja selgitada seosed keha koostise, mobiilsuse ja vere biokeemiliste näitajate ning kehalise aktiivsuse vahel vanemaealistel tervetel naistel. Töös püstitati järgmised konkreetset ülesanded:

1. Võrrelda keha koostise, motoorse võimekuse ja mobiilsuse näitajaid erinevalt treninitud vanemaealistel naistel ning leida võimalikud seosed lihasjõu ja mobiilsuse näitajate vahel;
2. Leida erinevused keha koostise näitajates ja mobiilsuse parameetrites erineva mõõduka ja tugeva intensiivsusega kehalise aktiivsusega

- vanemaealistel naistel ning leida seosed mobiilsuse parameetrite ja kehalise aktiivsuse näitajate vahel;
3. Leida seosed vere biokeemiliste näitajate ja kehalise aktiivsuse parameetrite vahel erineva kehalise aktiivsusega vanemaealistel naistel.

### **Vaatlusalused ja meetodika**

Töö põhineb kahel erineval uuringul. Esimeses uuringus osalesid 32 vabahtlikku, kes jagati kahte gruppi vastavalt osalejate pikaajalisele kehalise aktiivsusele: regulaarselt treenivad ja mitte treenivad vanemaealised naised. Regulaarselt treenivad vanemaealised naised treenisid vähemalt kaks korda nädalas ning ühe treeningu kestus oli minimaalselt 60 minutit. Sellist treening režiimi olid osalejad jälginud vähemalt 5 aastat enne uuringusse kaasamist. Mitte treenivad naised ei treeninud regulaarselt ega ei olnud treeninud regulaarselt viimase viie aasta jooksul või olid sooritanud ühe kuni 30 minutilise treeningu nädalas. Uuringus osalejatel määrati keha koostis ja luutihedus DXA meetodiga: kogu keha rasvamass, rasvaprotsent, rasvavabamass ja luumass. Lihasjõu näitajad määrati dünamomeetritega: käelihaste haardejõud, alajäsemete sirutajalihaste isomeetiline jõud ning alajäsemete võimsuse määramiseks kasutati dünamograafilist platvormi. Mobiilsuse näitajate määramiseks sooritati kolm testi: istest püsti tõusmise test, tõuse ja kõnni test ning kuue minuti kõnni test.

Teises uuringus andis nõusoleku osalemiseks 81 vanemaealist naist. Uuringu osalejad jagati kolme gruppi vastavalt objektiivselt määratud mõõduka ja tugeva intensiivsusega kehalisele aktiivsusele (minutit/nädalas): kõrge, mõõduka ja tugeva intensiivsusega kehalise aktiivsusega grupp (vähemalt 150 minutit mõõduka ja tugeva intensiivsusega kehalist aktiivsust nädalas, seejuures kehalise aktiivsuses episoodid sooritatuna vähemalt 10 minutiliste osadena), keskmise kehalise aktiivsusega grupp (10–149 minutit mõõduka ja kõrge intensiivsusega kehalist aktiivsust nädalas) ja madala kehalise aktiivsuse grupp (mitte ühtegi vähemalt 10 minutilist keskmise ja mõõduka kehalise aktiivsuse episoodi nädalas). Uuringus osalejatel määrati keha koostis DXA meetodiga, mobiilsuse näitajad, kehaline aktiivsus aktiseleromeetriga: mitteaktiivne aeg, madala intensiivsusega kehaline aktiivsus, mõõduka intensiivsusega kehaline aktiivsus ja kõrge intensiivsusega kehaline aktiivsus ning mõõduka ja tugeva intensiivsusega kehaline aktiivsus. Lisaks määrati veeniverest biokeemilised näitajad: resitiin, leptiin, C-reaktiivne valk ja tuumor nekroosis faktor alfa.

### **Järeldused**

1. Pikaajaliselt treeninud vanemaealistel naistel on paremad keha koostise näitajad, suuremad alajäsemete lihasjõu, lihaskvaliteedi näitajad ning paremad tulemused mobiilsuse näitajates võrreldes mittetreenitud vanemaealiste

- naistega. Mobiilsuse parameetrid on seotud alajäsemete lihasjõu- ja võimsuse näitajatega;
2. Mõõduka ja tugeva intensiivsusega kehaline aktiivsus on seotud mobiilsuse näitajatega vanemaealistel naistel. Mõõduka ja tugeva intensiivsusega kehaline aktiivsus, sooritatuna vähemalt 10 minutiliste osadena on seotud parema keha koostise ja mobiilsuse näitajatega. Kerge intensiivsusega kehaline aktiivsus ei korreleerunud mobiilsuse näitajatega tervetel vanemaealistel naistel;
  3. Resistiini kontsentratsioon veres korreleerus negatiivselt sammude arvuga päevas vanemaealistel tervetel naistel. Kehaline aktiivsus on seostatud tervislikuma resistiini kontsentratsiooniga ja võib seeläbi vähendada haigestumise riski.



## **ACKNOWLEDGEMENTS**

I am very grateful and would like to express my sincerest gratitude to:

- my academic supervisors Professor Jaak Jürimäe and Professor Mati Pääsuke for their valuable advice, consistent support and help throughout the process of conducting the studies, publishing the results and writing the thesis;
- my co-authors for all their help;
- all subjects volunteered to participated in the study;
- my family and friends for their support.

This study was supported by the institutional research funding IUT 20-58 of the Estonian Ministry of Education.



## **PUBLICATIONS**

## CURRICULUM VITAE

Name: Anni Rava  
Date of Birth: July 25, 1990  
Citizenship: Estonian  
Phone: +372 58 505 309  
E-mail: ravaanni@gmail.com

### **Educational Career:**

2015–2019 Doctoral studies, Institute of Sport Sciences and Physiotherapy,  
Faculty of Medicine, University of Tartu, Estonia  
2012–2015 Master studies, Faculty of Exercise and Sport Sciences,  
Physical Education and Sport, University of Tartu, Estonia  
2009–2012 Bachelor studies, Faculty of Exercise and Sport Sciences,  
Physical Education and Sport, University of Tartu, Estonia  
2000–2009 Pärnu Koidula Gymnasium

### **Languages:**

Estonian (native language)  
English (very good)  
Russian (basic)

### **Professional Career:**

2016– Clinical Data Manager, StatFinn

## ELULOOKIRJELDUS

Nimi: Anni Rava  
Sünniaeg: 25 juuli 1990  
Kodakondsus: Eesti  
Telefon: +372 58 505 309  
E-mail: ravaanni@gmail.com

### Haridustee:

2015–2019 Doktoriõpe, Meditsiiniteaduste valdkond, Liikumis- ja sporditeadused, Tartu Ülikool  
2012–2015 Magistriõpe, Kehakultuuriteaduskond, Kehaline kasvatus ja sport, Tartu Ülikool  
2009–2012 Bakalaureuseõpe, Kehakultuuriteaduskond, Kehaline kasvatus ja sport, Tartu Ülikool  
2000–2009 Pärnu Koidula Gümnaasium

### Keelteoskus:

Eesti keel (emakeel)  
Inglise keel (väga hea)  
Vene keel (algtaase)

### Töökogemus:

2016– Kliiniliste uuringute andmehaldur, StatFinn

## DISSERTATIONES KINESIOLOGIAE UNIVERSITATIS TARTUENSIS

1. **Lennart Raudsepp.** Physical activity, somatic characteristics, fitness and motor skill development in prepubertal children. Tartu, 1996, 138 p.
2. **Vello Hein.** Joint mobility in trunk forward flexion: methods and evaluation. Tartu, 1998, 107 p.
3. **Leila Oja.** Physical development and school readiness of children in transition from preschool to school. Tartu, 2002, 147 p.
4. **Helena Gapeyeva.** Knee extensor muscle function after arthroscopic partial meniscectomy. Tartu, 2002, 113 p.
5. **Roomet Viira.** Physical activity, ecological system model determinants and physical self-perception profile in early adolescence. Tartu, 2003, 167 p.
6. **Ando Pehme.** Effect of mechanical loading and ageing on myosin heavy chain turnover rate in fast-twitch skeletal muscle. Tartu, 2004, 121 p.
7. **Priit Kaasik.** Composition and turnover of myofibrillar proteins in volume – overtrained and glucocorticoid caused myopathic skeletal muscle. Tartu, 2004, 123 p.
8. **Jarek Mäestu.** The perceived recovery-stress state and selected hormonal markers of training stress in highly trained male rowers. Tartu, 2004, 109 p.
9. **Karin Alev.** Difference between myosin light and heavy chain isoforms patterns in fast- and slow-twitch skeletal muscle: effect of endurance training. Tartu, 2005, 117 p.
10. **Kristjan Kais.** Precompetitive state anxiety, self-confidence and athletic performance in volleyball and basketball players. Tartu, 2005, 99 p.
11. **Aire Leppik.** Changes in anthropometry, somatotype and body composition during puberty: a longitudinal study. Tartu, 2005, 161 p.
12. **Jaan Ereline.** Contractile properties of human skeletal muscles: Association with sports training, fatigue and posttetanic potentiation. Tartu, 2006, 133 p.
13. **Andre Koka.** The role of perceived teacher feedback and perceived learning environment on intrinsic motivation in physical education. Tartu, 2006, 137 p.
14. **Priit Purge.** Performance, mood state and selected hormonal parameters during the rowing season in elite male rowers. Tartu, 2006, 101 p.
15. **Saima Kuu.** Age-related contractile changes in plantarflexor muscles in women: associations with postactivation potentiation and recreational physical activity. Tartu, 2006, 101 p.
16. **Raivo Puhke.** Adaptive changes of myosin isoforms in response to long-term strength training in skeletal muscle of middle-aged persons. Tartu, 2006, 99 p.

17. **Eva-Maria Riso.** The effect of glucocorticoid myopathy, unloading and re-loading on the skeletal muscle contractile apparatus and extracellular matrix. Tartu, 2007, 114 p.
18. **Terje Sööt.** Bone mineral values in young females with different physical activity patterns: association with body composition, leg strength and selected hormonal parameters. Tartu, 2007, 94 p.
19. **Karin Tammik.** Neuromuscular function in children with spastic diplegic cerebral palsy. Tartu, 2007, 102 p.
20. **Meeli Saar.** The relationships between anthropometry, physical activity and motor ability in 10–17-year-olds. Tartu, 2008, 96 p.
21. **Triin Pomerants.** Ghrelin concentration in boys at different pubertal stages: relationships with growth factors, bone mineral density and physical activity. Tartu, 2008, 80 p.
22. **Tatjana Kums.** Musculo-skeletal function in young gymnasts: association with training loads and low-back pain. Tartu, 2008, 128 p.
23. **Maret Pihu.** The components of social-cognitive models of motivation in predicting physical activity behaviour among school students. Tartu, 2009, 116 p.
24. **Peep Päll.** Physical activity and motor skill development in children. Tartu, 2009, 102 p.
25. **Milvi Visnapuu.** Relationships of anthropometrical characteristics with basic and specific motor abilities in young handball players. Tartu, 2009, 114 p.
26. **Rita Gruodyté.** Relationships between bone parameters, jumping height and hormonal indices in adolescent female athletes. Tartu, 2010, 82 p.
27. **Ragnar Viir.** The effect of different body positions and of water immersion on the mechanical characteristics of passive skeletal muscle. Tartu, 2010, 142 p.
28. **Iti Määrsepp.** Sensorimotor and social functioning in children with developmental speech and language disorders. Tartu, 2011, 90 p.
29. **Ege Johanson.** Back extensor muscle fatigability and postural control in people with low back pain. Tartu, 2011, 106 p.
30. **Evelin Lätt.** Selected anthropometrical, physiological and biomechanical parameters as predictors of swimming performance in young swimmers. Tartu, 2011, 90 p.
31. **Raul Rämson.** Adaptation of selected blood biochemical stress and energy turnover markers to different training regimens in highly trained male rowers. Tartu, 2011, 84 p.
32. **Helen Jõesaar.** The effects of perceived peer motivational climate, autonomy support from coach, basic need satisfaction, and intrinsic motivation on persistence in sport. Tartu, 2012, 108 p.
33. **Sille Vaiksaar.** Effect of menstrual cycle phase and oral contraceptive use on selected performance parameters in female rowers. Tartu, 2012, 86 p.

34. **Anna-Liisa Parm.** Bone mineralization in rhythmic gymnasts before puberty: associations with selected anthropometrical, body compositional and hormonal parameters. Tartu, 2012, 96 p.
35. **Jelena Sokk.** Shoulder function in patients with frozen shoulder syndrome: the effect of conservative treatment and manipulation under general anaesthesia. Tartu, 2012, 125 p.
36. **Helena Liiv.** Anthropometry, body composition and aerobic capacity in elite DanceSport athletes compared with ballet and contemporary dancers. Tartu, 2014, 80 p.
37. **Liina Remmel.** Relationships between inflammatory markers, body composition, bone health and cardiorespiratory fitness in 10- to 11-year old overweight and normal weight boys. Tartu, 2014, 94 p.
38. **Doris Vahtrik.** Leg muscle function in relation to gait and standing balance following total knee arthroplasty in women. Tartu, 2014, 105 p.
39. **Artūrs Ivuškāns.** Bone mineral parameters in 11–13-year-old boys: associations with body composition and physical activity. Tartu, 2014, 95 p.
40. **Antonio Cicchella.** Relationships of multifunctional hormone leptin with anthropometry, aerobic capacity and physical activity in peripubertal boys. Tartu, 2014, 87 p.
41. **Martin Mooses.** Anthropometric and physiological determinants of running economy and performance from Estonian recreational to Kenyan national level distance runners. Tartu, 2014, 94 p.
42. **Triin Rääsk.** Subjectively and objectively measured physical activity and its relationships with overweight and obesity in adolescent boys. Tartu, 2016, 124 p.
43. **Donvina Vaitkevičiūtė.** Bone mineralization in boys during puberty: associations with body composition, physical activity and selected bone and adipose tissue biochemical markers. Tartu, 2016, 92 p.
44. **Kerli Mooses.** Physical activity and sedentary time of 7–13 year-old Estonian students in different school day segments and compliance with physical activity recommendations. Tartu, 2017, 84 p.
45. **Eva Mengel.** Longitudinal changes in bone mineral characteristics in boys with obesity and with different body mass index gain during pubertal maturation: associations with body composition and inflammatory biomarkers. Tartu, 2018, 113 p.
46. **Martin Aedma.** Assessment of the impact of selected dietary supplements on upper-body anaerobic power in wrestlers in simulated competition-day conditions. Tartu, 2018, 112 p.
47. **Henri Tilga.** Effects of perceived autonomy-supportive and controlling behaviour from physical education teachers on students' psychological needs and health-related quality of life. Tartu, 2019, 135 p.