Stretch-shortening cycle (SSC) muscle power, muscle strength and functional capacity in Scandinavian women and men - Effects of ageing

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“With mirth and laughter let old wrinkles come”
William Shakespeare

Till min älskade dotter, far och mor, familj och fantastiska vänner

Abstract

Introduction: Ageing is associated with a gradual decline in physical function due to age-related loss of muscle mass, strength, and muscle power, leading to loss of independence. Physical therapists employ various tests to assess physical functional performance, postural control, and muscle strength. Several of these may provide inadequate information in regard to detecting early onset of decline in performance. This information is important in respect to potential countermeasures in attenuating age-related disability. When approaching the 8th decade, the age-related decline in functional capacity appears to accelerate, while at the same time maximal lower limb Stretch-shortening cycle muscle power (SSC Ppeak) contributes more strongly to balance, gait speed and jump height, suggesting a threshold and critical age of ~ 75 years. Physical activity, particularly resistance training involving high-intensity muscle actions (i.e., heavy-resistance strength training) has proven effective in reversing the negative effects age-related changes, sedentary lifestyle and immobilization, even in older adults.

Objective: The aim of the present thesis was to investigate SSC muscle power production in a coupled eccentric-concentric muscle contraction across the full adult age span and between gender and how this contributes to different clinical outcome measures. Moreover, the aim was to investigate how immobilization affected physical performance, postural control, and muscle power in both young and old men, and investigate resistance training effect as a countermeasure to this immobilization. Additional aims were to investigate the relationship between health-related quality of life and physical performance in a cohort of old adults and further, whether old healthy individuals differ from a group of individuals with disabilities after stroke in terms of the relationship between comfortable and maximum gait speed.

Methods: Five cohorts, with young and old adults in two of them, and old adults only in the three remaining, with women and men represented in four of the studies. As a control group for one of the substudies, a group of elderly individuals with disabilities after stroke was included. Descriptive data was collected for all groups. Data for muscle power, physical performance, strength and quality of life was collected. In the intervention study the subjects underwent immobilization and then re-training.

Results: The study findings indicate that functional capacity appears to deteriorate at an accelerated rate around the 8th decade, whilst at the same time maximal lower limb SSC Ppeak appears to become a stronger contributor to gait speed and postural control. The result also suggests that both vertical jump height and maximum horizontal gait speed can be used as a proxy for lower limb SSC muscle power. Moreover, the results showed that men had a steeper age-related decline in SSC Ppeak compared to women. Gait speed was shown to correlate with physical health-related quality

of life. Further, it was shown that four weeks of active retraining involving high-intensity muscle actions (i.e., heavy-resistance strength training) is effective of reversing the negative effects of short-term (2 wk) immobilization on muscle power, postural control, and functional performance in both young and old adults. There was a moderate correlation between comfortable and maximum walking speed in the group of healthy elderly, while the corresponding correlation in the stroke group was strong.

Conclusion: The novel finding in this thesis was that men showed ~50% greater age-related decline rate in SSC Ppeak (W/kg/year) compared with women. SSC Ppeak was severely affected by aging irrespectively of gender, with a reduction for individuals in the 8^{th} decade by ~50% compared with subjects in their 2^{nd} decade. It appears that when approaching the 8th decade, the age-related decline in functional capacity accelerates, while at the same time SSC Ppeak contribute more strongly to balance and gait capacity, suggesting a threshold and critical age. Vertical jump height is suggested to serve as a proxy measure for SSC Ppeak in clinical settings. Horizontal gait speed and physical health-related quality of life can provide as useful tools together with jump height to identify early stages of frailty and increase health-related quality of life even in the oldest-old. Short-term immobilization (2 wks.) of unilateral lower limb reduced maximal leg extensor power in both young (-17%) and older (-15%) men and affected postural control to a greater extent in old men than young. However, four weeks of supervised resistance-based retraining restored leg extension power and postural control in both young and old men and produced physical performance gains and improved maximal gait speed in the older men. The correlation between comfortable and maximum gait speed was shown to be moderate in community dwelling older persons and strong in chronic stroke sufferers.

Sammanfattning på svenska

Introduktion: Åldrande är förknippat med en gradvis försämrad funktionsförmåga på grund av åldersrelaterad förlust av muskelmassa, styrka och muskelkraft, vilket på sikt kan leda till minskad autonomitet. Fysioterapeuter använder olika funktionstester för att bedöma fysisk funktionell prestation, postural kontroll och muskelstyrka. Det är möjligt att dessa inte är tillräckligt känsliga för att mäta små förändringar över tid om de inte utförs till personens maximala förmåga (kapacitet), och kan således ge otillräcklig information för tidig upptäckt av begynnande nedåtgående funktionsförmåga. Utvärdering över tid är viktigt med hänsyn till möjligheten att initiera insatser och åtgärder som kan bromsa och motverka åldersrelaterad funktionsnedsättning. När man når ~75 år verkar det som om försämringen av funktion accelererar, samtidigt som maximal muskelkraft i nedre extremiteten i större utsträckning bidrar till balans, gånghastighet och hopphöjd, vilket tyder på en kritisk ålderströskel. Fysisk aktivitet, särskilt styrketräning som involverar snabba rörelser (explosiv muskelaktivitet, särskilt explosiv styrketräning (snabba rörelser) har visat sig vara effektiv för att vända och/ eller bromsa de negativa effekterna av åldersrelaterade förändringar och immobilisering även hos äldre vuxna.

Syfte: Syftet med denna avhandling var att undersöka den maximala muskelkraften i en Stretch-shortening cycel (SSC Ppeak) manöver genom excentriskt-koncentriskt muskelarbete i hela det vuxna åldersspannet samt mellan kön. Därtill, var syftet att studera hur mycket SSC Ppeak bidrar till olika kliniska funktionstest. Vidare analyserades hur immobilisering påverkade fysisk funktionsförmåga, postural kontroll och muskelstyrka hos både unga och gamla män, samt effekten av styrketräning som intervention för återträning efter immobilisering. Ytterligare syften var att undersöka sambandet mellan hälsorelaterad livskvalitet och fysisk prestation i en kohort av gamla vuxna samt studera hur en kohort äldre friska individer skiljer sig från en grupp individer med funktionsnedsättning efter stroke avseende relationen mellan komfortabel och maximal gånghastighet.

Metoder: Fem kohorter, med unga och gamla vuxna i två av dem, och endast gamla vuxna i de tre återstående, och kvinnor och män representerade i fyra av studierna. Som kontrollgrupp till en av delstudierna inkluderades en grupp äldre individer med funktionsnedsättning efter stroke. Deskriptiva data samlades in för alla grupper. Data avseende maximal muskelkraft, fysisk funktion, styrka och livskvalitet samlades in. I interventionsstudien genomgick försökspersonerna immobilisering följt av styrketräning.

Resultat: Aktuella studieresultat indikerar att fysisks funktionsförmåga försämras i snabbare takt omkring det åttonde årtiondet, samtidigt som SSC Ppeak i nedre extremiteten blir en allt starkare bidragande faktor till gånghastighet och postural kontroll. Resultaten tyder också på att både vertikal hopphöjd och maximal horisontell gånghastighet kan användas som ett mått på SSC Ppeak. Studieresultaten visade även att män hade en brantare åldersrelaterad minskning av SSC Ppeak jämfört med kvinnor. Gånghastighet visade sig korrelera med fysisk hälsorelaterad livskvalitet. Ytterligare studiefynd påvisade god effekt av fyra veckors styrketräning för att motverka negativa effekter av immobilisering avseende muskelkraft, postural kontroll och funktionsförmåga hos både unga och gamla vuxna. En moderat korrelation förelåg mellan komfortabel och maximal gånghastighet hos gruppen friska äldre, medans motsvarande korrelation hos stroke gruppen var stark.

Konklusion: Det nya fyndet i denna avhandling var att män uppvisade ~ 50% större åldersrelaterad nedgång i SSC Ppeak (W/kg/år) jämfört med kvinnor. SSC Ppeak påverkades i större utsträckning av åldrande oavsett kön, och minskningen blev större när man närmade sig det 80e levnadsåret med ~ 50% jämfört med individer i 20 års åldern. Det förefaller när man närmar sig det 80e levnadsåret accelererar den åldersrelaterade nedgången av fysisk funktionsförmåga, samtidigt som SSC Ppeak bidrar i större utsträckning till balans och gångförmåga, vilket tyder på en tröskel och kritisk ålder. Vertikal hopphöjd föreslås som ett substitut i kliniken för SSC Ppeak. Horisontell gånghastighet och hälsorelaterad livskvalitet kan tillsammans vara ett användbart verktyg ihop med hopphöjd för att tidigt identifiera nedåtgående funktionsförmåga och öka hälsorelaterad livskvalitet även i hos de äldsta gamla. Det visade sig att även kort immobiliseringstid (2 wks.) av ett ben ledde till försämrad maximal muskelkraft i extensorer, både hos unga (-17%) och äldre (-15%) män och påverkade postural kontroll i större utsträckning hos gamla än unga. Dock räckte fyra veckor av övervakad styrketräning återställde den maximala muskelkraft förmågan hos unga och äldre samt postural kontroll, där äldre uppvisade förbättrad funktionsförmåga och ökade sin gånghastighet. Självvald komfortabel gånghastighet tycks vara relaterat till maximal gånghastighet för både friska äldre personer och för patienter med kronisk funktionsnedsättning efter stroke.

List of publications

This thesis is based on the following papers referred to in the text by their roman numerals:

I. Edwén CE, Thorlund JB, Magnusson SP, Slinde F, Svantesson U, Hulthén L, Aagaard P. *Stretch-shortening cycle muscle power in women and men aged 18-81 years: Influence of age and gender*. Scandinavian Journal of Mededicin in Science Sports 24, 717-726, 2014.

II. Elam C, Aagaard P, Slinde F, Svantesson U, Hulthén L, Magnusson SP, Bunketorp Käll L. *The effects of ageing on functional capacity and stretch-shortening cycle muscle power*. J. Phys. Ther. Sci. in press 2021.

III. Whyte S, Lavender H, Elam C, Svantesson U. *Tests of muscle function and health related quality of life in healthy older adults in Sweden*. Isokinet Exerc Sci. 2020: 1-7.

IV. Elam C*, Hvid LG*, Christensen U, Kjær M, Magnusson SP, Aagaard P, Bunketorp Käll L‡, Suetta C‡. *Effects of age on muscle power, postural control and functional capacity after short-term immobilization and retraining.* Submitted.

V. Vive S, Elam C, Bunketorp Käll L. *Comfortable and maximum gait speed in individuals with chronic stroke and community-dwelling controls*. J Stroke Cerebrovasc Dis. 2021 Oct;30(10):106023.

Content

Abbreviations

BMI	Body Mass Index
BCG	Body Center of Gravity
CG	The center of gravity
CoM	Center of Mass
CON	Concentric
CoP	Center of Pressure
CNS	Centra Nervous System
CSA	Cross Sectional Area
ECC	Eccentric
EQ5D	European Quality of Life five-dimension questionnaire
F	Force
GRF	Ground Reaction Force
GS	Gait Speed
HRQOL	Health Related Quality of Life
IADL	Instrumental Activities of Daily Living
ICF	The International Classification of Functioning, Disability and Health
IGF-1	Insulin Growth Factor-1
LBM	Lean Body Mass
MN	Motor neuron
MPB	Muscle Protein Breakdown
MPS	Muscle Protein Synthesis
MU	Motor unit
MVC	Maximal Voluntary Contraction
MyHC	Myosin heavy chain
PA	Physical Activity
PB	Postural Balance
SSC	Stretch-shortening cycle
SF-36	36-Item Short Form Health Survey
SOLEO	Standing on One Leg Eyes Open
WHO	World Health Organization
TA	M. Tibialis Anterior
SOL	M. Soleus
RFD	Rate of Force Development
Ppeak	Peak Power
V	Velocity
MUAP	Motor Unit Action Potentials

Definition of concepts

Activity	The execution of a task or action by an individual.
Balance	Often synonymous with postural control in clinical setting. In the context of, research balance may be considered synonymous with postural stability or equilibrium.
Body Center of Gravity, BCG	Is a hypothetical point around which the force of gravity appears to act. It is point at which the combined mass of the body appears to be concentrated.
Capacity	Ability to execute a task or an action in a standardised environmental.
Center of mass, CoM	The spatial point (x,y,z) at which the weighted mass of all the segments of the body is represented.
Center of pressure, CoP	The point at which the ground reaction force impacts the base of support.
Disability	Limitation in performance of socially defined roles and tasks within a sociocultural and physical environment.
Frailty	A clinically recognizable condition in which the ability of the ageing person to cope with daily or acute stresses is compromised by the increased impairment resulting from age-related deterioration in physiological reserve and function across multiple organ systems.
Functioning	Umbrella term of Body Functions and Structures and Activities and Participation, positive aspects.
Functional limitations	Limitations in performance at the level of the whole person
Healthy aging	The biological process of getting older free from disease
Impairment	Problems in body function or structure as a significant deviation or loss.
Instrumental Activities of Daily Living, IADL	Things on does every day to take care of oneself and one's home. A way to measure how well a person can live by itself.
Lean Body Mass	Accounts for the nonfat cell mass and inter-cellular connective tissue.
Maximal Voluntary Contraction, MVC	The attempt to recruit as many fibers in a muscle as possible for the purpose of developing force.

Mobility limitations	Defined as difficutly performing a task such as stair climbing, walking and rising from a chair.
Motor Unit Action Potentials	The sum of the extracellular potentials of muscle fiber action potentials of a motor unit.
Muscle power	The product of force and velocity of muscle contraction.
Muscle strength	The ability to generate maximal muscle force expressed in Newtons or Newton-meters.
Participation	Involvement in a life situation.
Physical functional performance	An objectively measured whole body function related with mobility.
Performance	What a person does in his or her current environment.
Physical activity	All types of movement and activities performed at any level of skills for everybody.
Postural control	The ability to maintain the body in both static and dynamic conditions in a spatial equilibrium.
Primary ageing	Charecterized by a inevitable and complex intrinsic progressive decline in most physiological systems independent from disease.
Secondary ageing	Caused by environmental factors such as smoking and sedentary behaviour and disease.
Sedentary behaviour	Low energy expenditure (< 1.5 Metabolic Equivalents) activities during waking hours while in a seated, reclining, or lying position.

1. Introduction

In the past century persons aged 60 years and older represent the fastest growing population world wide due to an increase in life expectancy (Figure 1). Thus, the postponement or prevention of mobility limitations for the ageing population should be of strong public health interest. The ability to move without assistance is critical for maintaining autonomity and an independent lifestyle absent of "mobility limitations", defined as difficutly in performing tasks instrumental of daily living (IADL) such as stair climbing, walking and rising from a chair [1]. The common denominator for these activities is that they all require a certain minimum of lower limb muscle strength and power, respectively [2]. Limitations in these physical abilities increase the risk of falls, loss of autonomity, increased co-morbidity and premature death [3]. Given that in Sweden a majority of elderly live in ordinary housing conditions, initatives to meet future needs have to be adressed that will include early detection of deteriorating physical function and involve targeted and specifik exercise training [4].

Physical therapists and other health care professionals use a wide aray of physical tests and assesment tools to evaluate maximal muscle strength, postural balance and functional performance such as maximal and/or habitual walking speed. Albeit, although such tests are both validated and deemed reliable they often provide limited information only. In order to detect early onset of deteriorating physical function, a given test need to put the person at his/her maximum capacity. For the ageing individual signs of diminished functional capacity may be most apparent when functional performance is charged to its limit, such as trying to regain balance after tripping or avoiding obstacles during gait where the ability to generate steep rises in muscle force during minimum time intervals may be of essence [5-9]. Deteriorating health and mobility limitations eventually leading to increased needs of care represents marked challenges both for the health care system and increase of cost.

1.1. Ageing

It is well established that ageing is charecterized by a complex intrinsic progressive decline in most physiological systems [5, 10, 11]. This in turn leads to impairment due to a loss of tissue as well as function at a systematic level. Ageing at the individual level comprises the progression of into mobility limitations [12]. A large number of studies have established muscle strength (the ability to generate muscle force) as a main determinant of functional performance in aging individuals [12-21]. However, maximal muscle power (the peak product of force and velocity of muscle contraction) has been shown to decline at an earlier onset and with a steeper decline than muscle strength with ageing [10]. Granting that the increase in life expectancy observed during the last 5-10 decades can be considered a medical, social, and economic advancement, those extended years should be healthy and without disability. When discussed in this context ageing theories can be divided into *primary-*, and *secondary ageing* [22].

- *Primary ageing: characterized by a inevitable and complex intrinsic progressive decline in various physiological systems independent from disease [5, 10, 11, 23]*
- *Secondary ageing: caused by environmental factors such as smoking, sedentary behaviour and disease [22].*

In primary ageing the physiological changes represents inevitable processes, while a majority of factors responsible for secondary are reversible and sensitive to physical activity, nutrition, and other environmental factors. Hence, the age-related impairment in mechanical muscle function (strength, power, RFD) is due to degeneration in anatomical and/ or physiological systems (primary) while all influenced by lifestyle, biological and psychological factors (secondary). The many contributing factors to the accumulation of physical limitations with ageing have one hallmark factor in common, namely the loss in skeletal muscle mass, often referred to as sarcopenia [3, 24, 25].

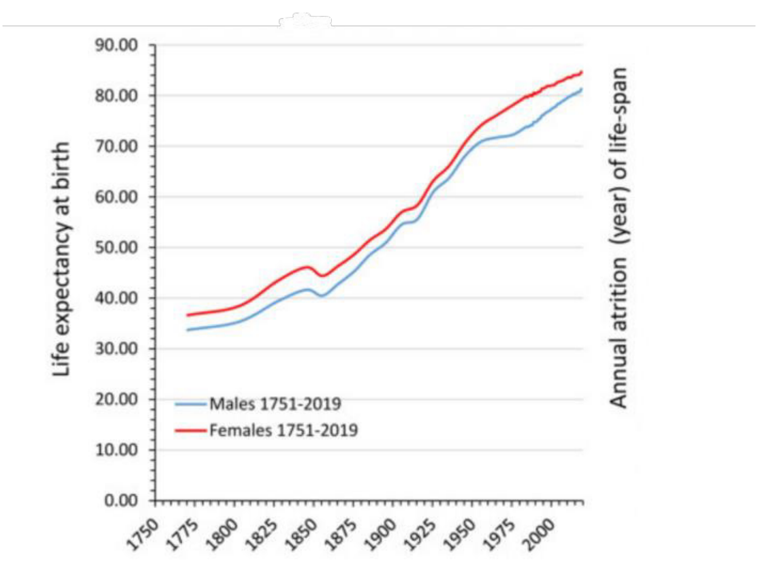

Figure 1. Swedish population statistics 1751–2019 shows the increase in expected lifespan at birth for women and men replotted from data replotted from Statistics Sweden (1999) and http://www.statistikdatabasen.scb.se/pxweb/en/ssd/ [26].

1.1.1. Ageing and changes in muscle mass

"Sarcopenia" was proposed in the late 1980's as a term for the loss of skeletal muscle mass associated with aging [27]. This term is specifically referring to the age-related loss of muscle fibers and overall muscle mass in the absence of any underlying condition and disease [10]. In later years, the definition of sarcopenia has extended to include the loss in muscle strength and physical function also associated with ageing [11, 28-30]. The aetiology of sarcopenia is complex involving vital physiological systems (neuronal, hormonal, immunological, nutritional) and comprising the effect of reduced physical activity [11].

Studies show that from the second to eight decade of life lean body mass (LBM) declines by 18% in men and 27% in women [24]. From the second to eight decade the difference in LBM between genders remains fairly constant with 64% LBM in women compared to men, which become statistically detectable after 45 years of age [11]. The loss in LBM leads to losses in functional performance in the elderly that are accompanied by reduced mobility, diminished quality of life, and increased incidence of fall-related injuries, the latter requiring costly hospitalization and extended rehabilitation efforts. Illogical as it may seem LBM decrease in the lower limb (~15%) to a greater extent than in the upper limb (~10%) in both women and men despite the continued use of the lower limbs for overground locomotion. The greater loss in the lower limbs may be due to a relative "deconditioning effect" induced by an increasingly sedentary behavior or simply result from a greater loss of motor units (MU) innervating the legs compared to the arms [11, 31]. Regardless, the loss in LBM results from a reduced number of muscle fibers and atrophy of those muscle fibers that are left together with an increased infiltration of non-contractile tissue (fat, collagen) [10]. These changes in muscle morphology have consequences for mechanical muscle function causing contraction speed and contractile force capacity to become reduced and thus leading to a progressive loss in functional performance [24]. Consequently, the ability to perform weight-bearing activities of daily living begin to decline [32]. Depending on the muscle a reduction in number of muscle fiber can have an early onset in age, like the rectus abdominis, while other muscles demonstrate a decline at a later stage in life, such as the quadriceps [10].

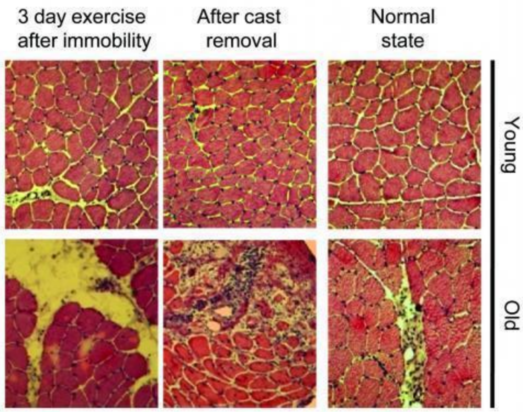

Figure 2. The difference between young and old muscle after immobilization and normal state. With permission figure applied from Carlson & Conboy, FASEB J 2004

1.1.2. *Ageing pathways and processes*

One of the most important factors in the aetiology of sarcopenia is the neuropathic process as it is responsible for the degenerations of α-motor neurons (MN) and the denervation of muscle fibers, which in turn lead to a reduction in the number of functioning motor units (MUs) [11]. The MNs innervate skeletal muscle and cause muscle contraction that generates movement. The MN and its effector, skeletal muscle fibers are referred to as a motor unit (MU). As a MU is activated, all of its fibers contract and the summated contraction force is controlled by the number of activated MUs. Gradual loss of spinal motor neurons (MNs) represents one of main characteristics of advanced aging. This is due to *apoptosis* of MNs and reduction in *insulin-like growth factor-1 signaling* (IGF-1) together with an elevation of circulating *cytokines* and increased levels of *oxidative stress* in and around the myofibers [10].

Motor neurons are divided into upper level or lower level MNs. Together they control both voluntary and involuntary movements where the upper MN is responsible for transmitting a signal to the lower MN further to the effector muscle to perform a movement. In animal studies (rats) peripheral nerves show infiltration of connective tissue with ageing together with a decrease in myelination and reduced axon density [33]. The decrease of fatty sheath (myelination) surrounding the neuronal process and fibers leads to reduced electrical transmission [34]. In animal studies a decline in number of MUs in old animals compared to younger animals demonstrated a 30 – 40 % reduction in MUs [35].

Early human studies noted in those 60 to 96 years of age a marked reduction in the number of functioning MUs and that they amounted to as little as 30% in the lower extremity muscles than that observed in younger individuals aged 3 – 60 years [36].Based on human autopsy data from the lumbospinal segment the loss of MNs was negible up to the age of 60 years and once past that age it was a notable decrease for each decade, from the 2^{nd} to the 10^{th} decade the average loss was 25% with extremes between 5 – 50% [37].

Likewise, experimental animal studies have reported reduced numbers of spinal MNs innervating the muscles of the lower limb at increasing age that were reduced at an accelerated rate in the final third part of their life [38].

The ankle dorsiflexor, tibialis anterior (TA) muscle controls the foot's position during the swing phase and absorbs energy during the stance phase [39]. In a recent cross-sectional study the number of functioning MUs were 39% reduced in the TA muscle of old individuals (61 – 69 years) compared to younger individuals in their 20s, and an even greater decline (61%) in MU numbers were observed in old adults aged 80 – 89 years [39]. McNeil et al. (2005) also observed a progressive reduction in the amount of functioning MUs with increasing age [40]. Notably, MU numbers remained similar in young and old men, however, were significantly reduced in very old men (Figure 2). These findings suggest that a progressive loss of MUs in the TA may not reach any detrimental effect on physical function until a critical threshold is reached [40].

The plantar flexor soleus (SOL) muscle is important for the push-off phase in human gait. Dalton et al. 2008 showed no difference in MU number estimated in SOL when comparing old (75 years) and young (27 years) adults [41]. However, Vandervoort & McComas (1986) observed reduced MU number in the SOL of 90 year old individuals compared to young and middle aged individuals (5 – 50 years) [42]. Collectively, these observations suggests that in aging humans the number of MU may start to decline at a slightly older age for SOL than TA [41]. The recruitment of ankle plantar flexor muscle is critical for propulsion in walking as well as for ensuring postural balance and is often impaired in post-stroke [43].

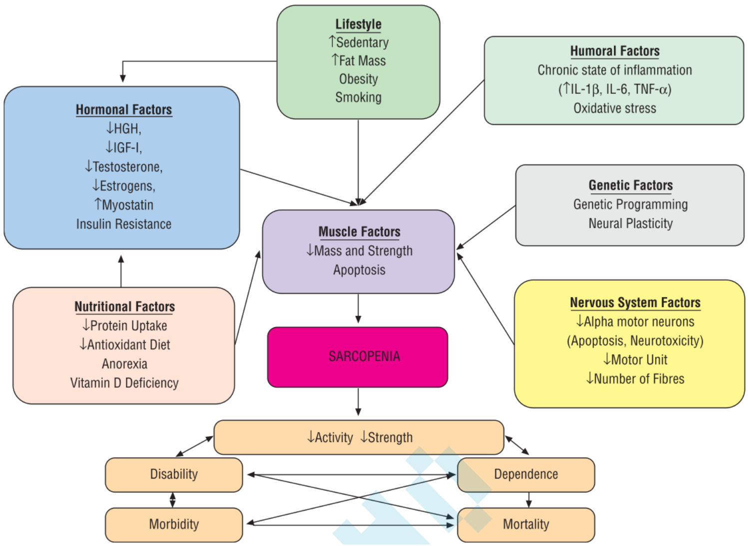

Figure 3. Scheme of etiological mechanism related to sarcopenia and their consequences. With permission adapted from Beas-Jimenez et al. 2011 [44].

During the human lifespan, denervation and reinnervation of skeletal muscle fibers occur in a continuous cycle [45]. However, in old age this balance seems to falter and the process of reinnervation become slower than that of denervation, contributing to an accelerated loss of myofibers [11]. The motor axon, i.e., afferent nerve fiber, carries electric nerve impulses (motor unit action potentials: MUAPs) from the MN to the muscle, the activation of a MN leads to a contraction of all muscle fibers supplied by its axon. In some cases muscle fibers that have been denervated can get reinnervated where surviving motor axons collaterally sprout their axons to re-innervate abandoned myofibers, hence resulting in very large MUs [46]. Despite a reduction of 40% in MU number in old humans maximal muscle strength (MVC) was similar to that of young subjects whereas when a reduction in old reached 60% of MU it was accompanied by substantial impairments, suggesting a critical threshold of 50% of MUs [40] (Figure 4). It seems that axonal sprouting becomes inadequate at advanced age leading to gradual loss of MUs which in turn lead to a significant loss of muscle fibers followed by a decrease in muscle mass and strength and in the long run leading to functional disability [40]. A limitation in physical capacity will lead to an increased risk of loss off autonomy and risk of falls [3, 44] (Figure 3).

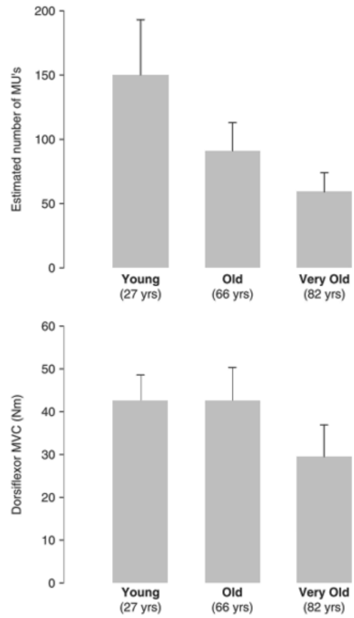

Figure 4. Estimated number of functioning motor units (MUs) in the anterior tibialis (TA) muscle (top panel) and maximal isometric TA muscle strength (MVC; bottom panel) observed in young (23-32 yrs), old (61-69 yrs) and very old (80-89 yrs) adults. With permission data from McNeil et al. 2005 [40].

Insulin-like growth factor-1 (IGF-1) is primarily produced in the liver and skeletal muscle that responds to growth hormone stimuli. It helps stimulate normal bone and tissue growth and development. As IGF-1 has an effect on the myelination of motor axon, apoptosis, repair of axons and axonal sprouting a decrease in the production in ageing individuals it can have significant implications in prevention and adaptive compensation on spinal MNs [10, 47]. It is well documented that IGF-1 play a particular role in muscle hypertrophy due to their anabolic effect as they cause a net increase in protein content [43]. Especially exercise involving a stretch cycle increases a specific isoform of IGF-1 for the muscle [48]. In elderly there is a reduction in endocrine and paracrine (local muscle) production of IGF-1, which can have an effect on the prevention as well as the adaptive compensation for the loss of MN with ageing as IGF-1 has a potent effect on motor axon myelination, MN apoptosis, stimulation of axonal sprouting, and repair of damaged axons [10, 47]. It has been suggested in experimental animal studies that IGF-1 stimulates axonal collateral sprouting to innervate denervated muscle fibers, which partly could compensate for the loss of MNs up to a certain point [49].

One of the main strategies to counteract ageing muscle decline is physical activity (PA) [50]. Physical activity can reduce age-related oxidative damage and chronic inflammation and improve the IGF-1 signaling pathway [51]. It has been suggested that high IGF-1 levels may increase muscle mass and decrease the risk of muscle weakness.

Cytokines are the first messenger of intercellular communication released by cells as secreted protein. It can be divided into pro- and anti-inflammatory varieties. There is ample evidence that it plays a substantial role in muscle growth and wasting [52]. Some suggestions of association between a reduction in skeletal muscle performance and acute inflammation has been made, being a limiting factor on outcome of physical training in geriatric patients [53]. It is typically observed an elevated level of inflammatory cytokines in old individuals which can blunt the effects of IGF-1 in muscle tissue and might have similar effect on MN and its axon [47]. However, it remains to be determined to which extent local (paracrine) muscle IGF-1 isoforms produced by myofibers and/or ECM fibroblasts directly helps to maintain spinal MN integrity and function in ageing human individuals [47].

Oxidative stress is caused by an imbalance between the production and accumulation of oxygen reactive species in cells affecting the ability to detoxify these products. As the muscle contracts during exercise levels of reactive oxygen species is elevated in the muscle, leading to a reduction in force generation and increased muscle atrophy [54]. D'Antona et al. (2003) noted a significant relationship between the concentration of myosin and loss of specific force, where the concentration of myosin was lower in single muscle fibers in old subjects, and especially in immobilized old, compared to that in young subjects [55].Myosin heavy chain (MyHC) isoforms dictate muscle fiber type and can be identified even in a single muscle fiber [56]. Slow-oxidative muscle fibers (MyHC I) contracting relatively slowly and use aerobic respiration (oxygen and glucose). They are slow twitch muscle fibers, also known as type I fibers and describes the fact that they have a steady and slow contraction. They are primarily recruited for low-intensity and endurance work since they can keep working for long periods of time without fatiguing through aerobic processes [57]. Fast twitch muscle fibers can contract more rapidly and powerful and are needed for short intense activities like running, walking fast and chair raising. The fast oxidative glycolytic fibers (MyHC IIa) have fast contractions and primarily use aerobic respiration (O^2), while the fast glycolytic (MyHC IIx) muscle fiber is even faster and more powerful than type IIa and used for very short-duration high-intensity bursts of power and tires easily [57]. Mutliple fiber types are within a single muscle group but with different proportions of fiber types; MyHC I fiber type is dominant in the soleus muscle, while MyHC II is greater in the vastus lateralis muscle [58]. However, these proportions seem to be flexible and can remodel their phenotypes to different circumstances, including aging [59].

The preferential atrophy of fast-twitch muscle fiber indicates this fiber type to be more severely affected with ageing than the slower type I fibers [60]. The selective loss of fast type II fibers in the limbs cause general muscle weakness, reduced fatigue resistance, disturbed gait and impaired postural balance, which can lead to falls and fractures [43]. Aagaard et al. (1998) observed a positive relationship between the relative content of MHC II isoforms in the quadriceps muscle and maximal knee extensor strength produced at high contraction velocities. It was only in the faster contraction velocities this relationship was observed, whereas during the lower contractions velocities this correlation was absent [57]. As the fast type II fibers predominantly are involved in activities with short-lasting muscle excretions at higher intensity, a reduction of type II fibers may therefore result in a decreased of contractile force and contraction velocity (i.e., decrease of speed of movement)[61].

Ageing women has been thought to experience a relative greater loss of lean body mass than men and as the already having considerably smaller muscle mass throughout life, would be at greater risk of loss of independence [62]. Adding to that, the extended life expectancy for women put them at even a greater risk for loss of independency [63] [11]. However, more recently reports on preferential atrophy in type II fibers was observed in men only [64]. Edwén et al. (2010) noted in 354 subjects aged 18 – 81 years that although maximal stretch-shortening cycle (SSC) leg muscle power was greater in men across this age span, the gender difference progressively diminished as men showed an ~50% faster rate of decline in SSC power than women, supporting this notion [65].

1.1.3. Muscle mass and adipose tissue

Simultaneously with the age-related loss of muscle mass and strength there is a concomitant increase in adipose tissue abundance [66]. The combined infiltration of fat and connective tissue that accompanies the loss of muscle tissue with ageing is referred to as myosteatosis [67]. This shift has previously been shown to correlate with a decrease in physical function [68]. Apart from the reduction in physical function due to increased fat infiltration, age-related obesity potentially increase the risk of sustaining chronic disease conditions and increased mortality [69]. The transition in body composition with increasing age characterized by increases in fat tissue and loss of muscle mass often occurs without change in total body weight, for which reason Body Mass Index (BMI) may not be considered a reliable way to evaluate body composition in elderly [70]. The extra gravitational load imposed on the body restricts locomotion because of the added mass of inactive tissue. Increasing depots of body fat are often observed at old age, and believed to sustain sarcopenia by increasing systemic low-grade chronic inflammation [11] (Figure 2). There is an inverted relationship between accumulation of intramuscular fat, connective tissue and the level of physical activity (PA), where an increase in PA by double is found to half the amount of intramuscular fat and connective tissue [71] (Figure 2). The combination of sarcopenia and obesity is a condition also referred to sarcopenic obesity (SO) [72]. However, it has been demonstrated that ageing individuals have substantial adaptive capacity in their skeletal muscles, and that the neuromuscular system also demonstrate significant plasticity in response to resistance training that may compensate significantly for the age-related declines in neuromuscular function and muscle mass hence leading to improved functional performance, even at very old age [73] [10].

1.1.4. Ageing and physical function

It has previously been established that human ageing represents a complex progressive decline in large number of physiological systems [10, 11]. The changes in muscle fiber size and number discussed above results in changes in muscle architecture and lead to impaired mechanical muscle function [10, 11, 27, 74]. In turn, the impairment in muscle strength, power and RFD is translated into a progressive decline in instrumental activities of daily living (IADL) leading to a reduced ability to perform every day activities, such as stair walking and raising from a chair with increasing age [10, 14, 20, 75]. Being able to perform every day activities independently and stay autonomous with increasing age help to sustain a certain level of quality of life [76]. As physical functional deterioration develops gradually it may not be immediately apparent as older persons rarely performance tasks at their maximal capacity and slowing of movement comes gradually.

According to the original classification proposed by Nagi [77], functional limitations can be defined as *"limitations in performance at the level of the whole person"*. By contrast, disability is defined as *"limitation in performance of socially defined roles and tasks within a sociocultural and physical environment"*[77]. These distinct definitions are important, since functional limitation does not reflect how a person is actually coping in her or his environment, the actual place of the disability [78]. Nonetheless, the step between these two domains is clear and can be assessed by simple measurements that will provide a prospect to identify those at risk of loss of physical function. Notably, elderly subjects may be at different stages of loss in function leading to disability. Not too surprisingly, therefore, cross-sectional studies find only poor correlations between limitation in function and disability, and previous researchers have found that maximal muscle power may vary in its relationship to functional activities depending on the intensity of the activity [19, 78]. But from a therapist's point of view this observation is important, when examining and evaluating elderly with mild to moderate functional impairments. Many of the tests used today for assessment of physical functional performance are not putting the elderly person at his/her maximal capacity but are performed at "self-selected speed" or "comfortable pace". An argument for choosing such walking speeds has been that examining maximal speed intervals may influence a person's natural movement pattern, which however never has been demonstrated experimentally. In light of this, It would be more adequate to examine physical functional performance like gait speed at a higher/maximal intensity in elderly and old adults, thus better representing lower limb peak muscle power and thereby perhaps enable the physical therapist to better detect changes over time [19]. It has been argued that the progressive loss of MUs at increasing age may not lead to a decline in physical functional performance before a certain critical threshold is reached [10]. As discussed earlier, this

threshold appears to vary between different muscles, but seems to be encountered when there is a 50% decrease in MU number compared to healthy and young individuals [10, 40].
Given that skeletal muscle power is dependent on both muscle force production and contraction velocity and that maximal muscle power plays an important role for ADL function such as walking, getting on a bus, crossing the street and being able live to independently, it seems crucial to improve our understanding of the underlying changes and related contributing factors responsible for the loss in maximal muscle power with ageing and to examine how it relates to functional performance.

Myofibrillar protein synthesis is a biological process inside the cells to balance the continuous breakdown of myocellular proteins. Actin and myosin are molecules responsible for many types of cell movements, such as muscle contraction and force production [79]. Cellular structural proteins only exist for a certain time and are then discarded or recycled through the process of protein turnover. Dynamic balance in this system is important as proteins perform a number of important functions such as providing structure to cells, acting as enzymes or hormones. Muscle protein synthesis (MPS) is a metabolic process where amino acids are bound into cytoskeletal muscle proteins [80]. Muscle protein can roughly be divided into contractile *myofibrillar proteins* and energy producing *mitochondrial proteins.* It is the myofibrillar proteins that are primarily responsible for changes in skeletal muscle mass following resistance training (RT) whereas mitochondrial proteins primarily are found to be upregulated in response to endurance type training [81].

The net difference in the rate of MPS and muscle protein breakdown (MPB) constitutes the determining factor as to whether there is a gain or a loss in muscle protein and hence also in muscle mass over time [82]. The homeostasis of skeletal muscle mass is not only crucial to sustain locomotion and strength, but is also the largest metabolic tissue in the body, reducing risk of obesity, cardiovascular disease, insulin resistance, diabetes and osteoporosis [83]. Hence, to countermeausure sarcopenia it is of vital importance for strategies to preserve or increase skeletal muscle mass. Both nutrition and resistance type exercise have potent anabolic effects on skeletal muscle mass due to inducing marked increases in MPS, which is considered the dominant process in skeletal muscle remodeling in adult humans [84].

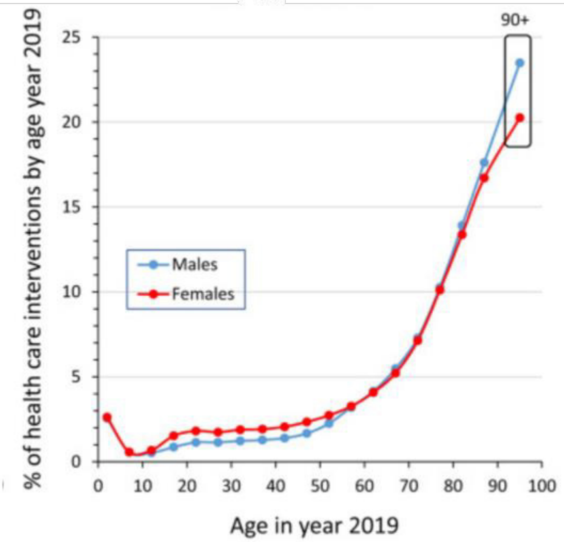

Figure 5. Swedish population statistics shows health care interventions by age and sex in 2019, reflecting the decrease and increase in mortality in early and late life, respectively (data from Statistics Sweden (1999) and http://www.statistikdatabasen.scb.se/pxweb/en/ssd/) [26].

1.2. Countermeasures towards neural, muscular, and functional impairments with ageing

1.2.1. Resistance training and physical activity

Some, but not all types of physical training and exercise are effective of evoking adaptive changes in muscles and the CNS to compensate for the aged-related loss of spinal MNs [10]. Depending on what one wants to achieve, different components of exercises can be employed. For instance, prolonged aerobic training with low-force contractions and low-frequency muscle fiber activation is known to stimulate muscle endurance as well as improve cardiovascular capacity, whereas resistance training with few high-force contraction and high-frequency muscle fiber activation for a short duration mainly targets strength development [10].

Even chronically trained master athletes and life-long strength-trained individuals show an age-related decrease in maximal muscle strength, power and RFD [85, 86]. However, their capacity to generate RFD remains substantially greater (4-fold elevated) compared to non-trained aged matched subjects [86, 87]. Further, 80-year old strength trained weight lifters were found to generate similar maximal muscle power as 60 year-old untrained individuals, suggesting that life-long strength training may compensate for up 20 years of age-related decline in muscle power [85]. Hence, it seems that resistance training (RT) is a highly effective counter measures to attenuate and slow the age-related decline in physical function, muscle strength/power/RFD and muscle mass [44, 70, 88, 89]. Muscle weakness is a treatable cause of disability and RT is considered a safe and effective exercise paradigm even in very old adults [73]. While reduced muscle power and explosive force capacity both have been associated with impaired functional performance, explosive-type RT has proven to enhance functional performance and reduce risk of falls in old individuals [90]. In example, 12 week low-frequency (twice a week) explosive-type RT produced substantial gains in both strength and power in old (60-65 yrs) and very old (80-89 yrs) women [73]. Further, individuals exposed to lifelong RT demonstrate enlarged myofiber size and enhanced mechanical muscle performance compared to age-matched non-exercising controls [91]. This relative preservation in muscle morphology and function may provide an important physical reserve, keeping functional performance above the critical threshold of autonomy when approaching old age. Following 12 weeks of explosive-type RT RFD was found to increase by 43% in untrained women aged 60-80 years, further supporting the notion that RT can effectively attenuate age related declines in mechanical muscle function [73]. Explosive-type RT can prepare even the oldest old to better develop muscle force rapidly (i.e. increasing RFD) during an unexpected postural perturbation and thereby may potentially help to prevent fall incidents.

Physical functional performance is defined as "*an objectively measured whole body function related with mobility*", going beyond muscle function measures as it involves many other organs and systems (balance, bones, neurology, cardiovascular, motivation) hence, being a multidimensional concept [92].The WHO defines activity limitations as *"problems in activity that occur as a result of an interaction between a health condition and the context in which the person exists"* [93]. Physical function is strongly and inversely associated with falls, hospitalization, and level of independence and even death in older persons [94]. Activities can be essential for maintaining autonomy or discretionary and although not always required for independent living, still appears to have a positive effect on quality of life [94]. Assessment of physical functional performance with valid and reliable methods that are easily administered could provide valuable information for identification of persons that would benefit from targeted physiotherapy and/ or other types of exercise-based intervention protocols. Hence, recognition to the importance of treatment of physical functional performance needs to be addressed as functional performance is a treatable issue.

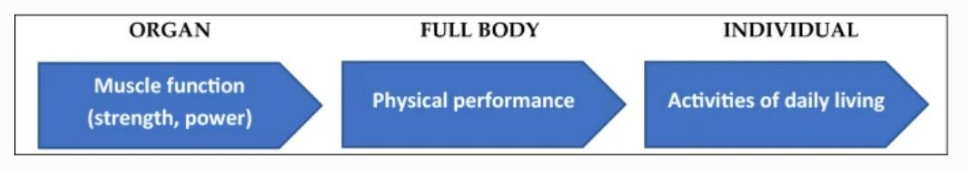

Figure 5. Hierarchy of age-related loss in physical performance. With permission from Beaudart et al. (2019) [92].

Physical activity (PA) is defined by WHO as "*all types of movement activities performed at any level of skill for everybody*" [95]. Regular PA is not only proven to prevent and manage a large number of life-style diseases and several types of cancers, but can also improve mental health, well-being, and quality of life [31]. However, according to WHO as little as 20% of adults globally engage in sufficient amounts of PA and in developing countries this number is even smaller. The lack of engagement in PA exerts a negative impact on a grander scale than individual health, as it also affects health systems, environment, and economic development [95].

1.2.2. Muscle strength

The ability to generate maximal force in a single muscle contraction (MVC) is referred to as maximal muscle strength. Summarizing current research has in regards to muscle power and functional capacity concluded that the relationship between the two are greater than that between muscle strength and functional capacity [96]. The natural biological deteriorating process in the neural system due to ageing contributes to a gradual impairment in mechanical lower limb muscle function (e.g. causing reduced muscle strength, power and RFD) [73, 97]. The reduction in muscle strength is greater than that of muscle size and consequently there is a decline in force per unit of muscle cross-sectional area (CSA) [98]. The disproportionate age-related loss of muscle strength compared to CSA can in part be explained by concurrent age-related modifications in neuromuscular function discussed above [99-101].

1.2.3. Muscle Power

Maximal muscle power is considered a predictor of functional performance and an important factor for functional capacity and the risk of falling [15, 20, 75]. Both animal and human study data support that distal lower limb muscles are more severely affected by age-related changes in maximal skeletal muscle power than proximal upper limb muscles [10, 102-104]. Muscle power is defined as the product of muscle force and muscle contraction velocity, and is considered functionally more relevant than maximal muscle strength *per se* [105, 106]. Performing physical demanding or reactive motor tasks require bouts of short-lasting forceful muscle exertions that are dependent on the muscles capacity to generate high muscle power [73]. Consequently, training programs aimed at reducing the risk of falls and increase functional ability in older adults should be designed to maximize muscle power and RFD rather than muscle strength [14, 107].

Human locomotion and consequently many activities of daily living consist of coupled eccentric-concentric muscle actions, also known as stretch-shortening cycle (SSC) movements [108-110] (elaborated below). Power-based muscle strength measurements have previously been shown to start decline at an earlier stage (+50 yr) than those measurements that are less power-based (+70 yr) [21]. Voluntary angular contractile velocity at a whole muscle level is slower in old individuals by approximately 15 – 40 % at a relative submaximal load compared to younger persons [106, 111-113]. Additionally, estimated maximum contraction velocity in different muscles are estimated to be 30 – 40% lower in healthy old individuals than in young adults [106, 114, 115]. A majority of studies report that single muscle fibers from old compared to young are slower in terms of maximum shortening velocity [86, 116-118]. In result, the force - velocity *(F-V)* relation is substantially affected by the age-related losses in both strength and shortening velocity, respectively [96]. Muscle force and contraction velocity are fundamental for the magnitude of power production and if any of these two factors are impaired with ageing, muscle power production is decreased [119]. Notably, the age-related loss in maximal power is greater than the respective declines in force and velocity alone [111].

1.2.4. Stretch-shortening cycle muscle actions

Human locomotion and many activities of daily living (ADL) utilize the Stretch-shortening cycle (SSC) with movements usually involving multiple joints (i.e. hip-knee-ankle). Such coupled eccentric-concentric muscle actions are typically termed Stretch-shortening cycle (SSC) movements, which are commonly encountered during ADLs [2, 120, 121]. Already in the mid-sixties Cavagna et al. (1965) pointed out based on animal studies that elevated work and enhanced power output could be produced in the shortening phase (concentric contraction, CON) of muscle contraction if preceded by an active s(eccentric contraction, ECC) [122-125].

A well-functioning neuromuscular capacity is of high importance to effectively utilize SSC muscle actions. Hence, the assessment of SSC maximal muscle power becomes an important diagnostic tool in the evaluation of neuromuscular function in the elderly and old adults, both in the clinical and scientific setting, respectively, as the age-related loss of MNs and the reduction in number of muscle fibers and size leads to an impaired muscle performance and attenuated power output (discussed in detail above). In result, reductions in functional capacity during everyday tasks may occur [10].

In humans there are three types of muscle actions. Depending on the external load, direction of action and magnitude, the muscle action have been given different names - concentric, isometric and eccentric. In humans there are primarily two types of muscle work utilized: concentric (positive) and eccentric (negative) [123]. Normal human muscle movement seldom involves a pure form of these types of muscle actions since humans are subjected to external force (e.g., gravity) impact of force (e.g., jumping and running) which lengthens as well as shortens the muscle. In general, the muscle action often take place in altering cycles, with the eccentric phase proceeding the concentric phase [123, 126]. It has been shown that this type of sequence, where *the eccentric muscle action is directly followed by a concentric muscle contraction,* can generate more explosive muscle force and power compared to an isolated concentric muscle contraction [123-125].

Early studies have shown that due to pre-activation (i.e. muscle pre-tensioning) and stored energy in series-elastic muscle-tendon structures , muscle work can be 100% greater during coupled eccentric-concentric contractions (SSC) compared to isolated concentric muscle actions [125]. Notably, a large number of typical daily activities involve SSC muscle actions, such as walking, running or stair climbing, which are all motor tasks requiring synchronization of muscle actions over several joints. Consequently, when evaluating functional performance in elderly is becomes important to include test measures that involve major joints and integrated SSC muscle actions. The Counter Movement Jump (CMJ) is a weight-bearing test often used to assess maximal SSC lower limb muscle power, measured as the *product of vertical ground reaction force and the vertical velocity of body center of mass [65, 120, 127, 128] (Study I)*. Notably, elderly women with a history of falls demonstrated a 24% lower peak power compared to women who had no history of falls, justifying muscle power testing to be an important tool in detecting age-related impairments in mechanical muscle function and functional performance, respectively [90].

1.2.5. Rate of force development (RFD)

The definition of "explosive" muscle strength is the *rate of rise in contractile force at the onset of contraction,* during the early phase (0-200 ms) of contraction, alas denoted the *rate of force development* (RFD) [129, 130]. In fast and forceful muscle contractions, RFD is of important functional significance as fast movements typically involve contractions times of 50-250 ms, which are much faster than the time it takes to reach maximal muscle force production (300-400 ms) following force onset [130] [131]. In the lab RFD is calculated as the slope of the moment-time curve (Δmoment/Δtime) or force-time curve (Δforce/Δtime) recorded during the rising phase (30-200 ms) of rapid MVC efforts.

The ability to voluntarily contract a muscle as rapidly as possible (i.e., at high volitional RFD) is important for example to maintain postural control with increasing age. During fast limb movements and very short contraction times maximal muscle force might not be reached. When put in context to our ageing population it could lead to greater risk for falls as the ability to generate rapid muscle force is reduced. This is partly due to an increased motor unit discharge rate, which with the right type of strength training (explosive-type and heavy-resistance) can be improved and contribute to the training-induced gain in RFD [130]. It seems that RFD is more strongly correlated to sport performance and ADLs than maximal isometric or concentric muscle strength (MVC) [132]. Thus, RFD may more sensitively detect acute and/ or chronic changes in neuromuscular function than testing of maximal force (MVC) per *se*. In the fields of rehabilitation and monitoring of physical function in elderly it thus may prove informative to quantify RFD during standardized and reproducible MVC efforts [132].

1.3. Gait speed and ageing

In quiet standing the body's center of gravity (BCG) is maintained steadily within the base of support. However, during frontal gait the BCG falls forward and is transiently shifted outside the base of support, hence representing a potentially unstable movement [133]. During normal walking 80% of the stride period involves unilateral stance, which makes walking a continuous pendulum between instability and stability [134]. Consequently, walking is a complex functional task where gait speed can reflect functional capacity, overall health and general well-being [135-137]. Slow gait speeds are associated with an increased incidence of falls and elevated risk of mortality [14, 137, 138]. Several factors affect gait speed apart from age-related decline in muscle function and the degenerative neuropathic process, such as visual system and cardiorespiratory fitness [11, 139, 140].

The age-related reduction in force production and contraction speed (i.e. reduced muscle power) result in an overall slowing of movement and is a fundamental marker of old age [10, 55, 141-143]. Other traits of gait that change with ageing is increased stance width, increased time spent in double support phase, increased bent posture and decrease in propulsive force production in the push-off phase. Evaluation of gait speed is frequently used in clinical settings for detecting potential impairments in health and physical function [144]. Being able to walk fast with brief bouts of high-intensity muscle actions can be closely related to the ability to generate high peak muscle power in older adults [145]. It has been suggested, therefore, that maximal horizontal gait speed should be the single parameter of choice when evaluating physical function in ageing populations [78]. Gait speed need to be put in an ecological context such as safely crossing a street, as it differs whether the person walk in a quite corridor or try to cross a busy street full of traffic. Studies have shown that older pedestrians and individuals with disability, such as stroke, are more likely to be seriously injured or die in traffic due to slower decision making and slower walking speeds [146, 147]. In Elam et al. (2021) (Study II) the oldest old managed to walk 1.71 m/s for women and 1.87 m/s for men, which was found to correlate positively with lower limb SSC muscle power (r=0.54; 65-81 yrs) [145]. In comparison with young persons (~20 yr) healthy persons in their 70s demonstrated a 10 to 20 percent reduction in gait speed [148, 149]. This can be compared to individuals with post-stroke where mean velocity in gait was 0.8 m/s [150]. In several countries it seems that green light crossing time for pedestrians is assumed to be a minimum of 1.2 m/s [151]. Reports on average gait speed for old pedestrians crossing a street averaged 1.4 m/s but they had a slower pace of 1.1 m/s during habitual gait [152]. This indicates that when walking speed is put in a context such as crossing a street, it puts a number of persons close to or beyond their threshold of physical capacity. Seasonal aspects must also be taken into account, especially in the northern hemisphere as there is a decrease in gait speed in winter [152].

One common post-stroke disability is hemiparesis with asymmetry and increased stride variability and muscle weakness [153, 154]. In older persons this asymmetry between limbs appears to be greater in fallers compared to non-fallers in Skelton et al. (2002) study [90] hence putting individuals with asymmetry from post-stroke or hip replacement at greater risk of falls during walking [154, 155]. In regards to perceived health and quality of life the authors concluded that gait speed had a strong correlation, especially for the measurement of vitality [156].

1.4. Postural control and ageing

The central nervous system (CNS) integrates sensory information from other systems in order to produce adequate motor output to maintain a controlled, upright posture, postural control [157]. In order to maintain postural control the body continuously moves even in the absence of external perturbations, a phenomenon known as “postural sway” [158, 159]. It has previously been suggested that when postural sway is minimal this reflects on the ability for postural control [160, 161]. All living life evolve in the presence of gravity and muscles act against gravity to stabilize the position of the different body segments. Hence, postural control comprise a complex integration of many bodily systems, sensory information from visual, vestibular and somatosensory are integrated to maintain equilibrium [162-164]. The human body resembles an inverted pendulum that is subjected to internal and external perturbations [165, 166].

Three major mechanisms contribute to generate stabilizing forces during human stance: 1) in response to visual, vestibular and somatosensory feedback there is a central activation of postural and stabilizing muscles; 2) the stretch reflex activates muscle by peripheral mechanisms; and 3) intrinsic stiffness about the ankle joint generated by the visco-elastic properties of the crossing muscles and connective tissue that mechanically resist even small movements [167]. In a controlled closed-loop these factors work together to generate the net ankle joint torque [165]. Somewhat surprisingly, no clear consensus and accepted definition of postural control or its underlying mechanisms seem to exist. Further, postural muscle activity and the system for ensuring postural equilibrium in the face of given internal or external perturbations have been lively debated. As nearly all bodily movements include a postural component to ensure equilibrium in upright balance, corrective and sometimes rapid ankle muscle forces and joint torques must be produced to keep an upright posture during sudden perturbations. As the ankle muscle generates corrective force to resist perturbations it allows us humans to keep our balance and proprioception plays an essential role in balance control why continuous calf muscle activity is required [168].

1.5. Disuse & sedentary behaviour

Bedrest and lack of gravitational impact forces typically resulting from infection, trauma or surgery are common in all age groups, although ageing individuals are more prone to bedrest due to a higher prevalence of comorbidity and hospitalization [101]. Individuals that are less likely to meet the recommended guidelines for PA are also more prone to have prolonged bouts of sedentary time compared to individuals that are more fit [31]. *Sedentary behaviour* can be described as sitting, television viewing, as well as couch time and is associated with at least 35 chronic diseases and clinical conditions [169]. The resulting lack of myogenic stimuli and gravitational impact loads can lead to both loss in muscle strength and postural control [170]. Skeletal muscle disuse is well known to result in impaired muscle contractile function for the lower limb in humans [171]. It has previously been suggested that the unloading (disuse) effect on skeletal muscle mass and muscle function substantially differ between young and old individuals [101]. One of the key points by Suetta et al. (2013) was that elderly a required longer recovery phase after short-term immobilisation than young in order to return to initial muscle mass levels [172].

Knee extensor muscle strength is important for everyday tasks such as chair rising, and decreases at a faster rate than muscle mass and volume, indicating a loss in muscle quality that seem to affect ageing individuals more than their young counterparts [101, 173, 174]. Further, available data show that the estimated number of MUs decrease to a greater extent in distal than proximal muscles [175]. Hence, the muscles essential for locomotion can approximately decrease by as much as 25% between the second to seventh decade [176].

It has been shown that the first days of acute disuse are the most critical with a rapid decline in muscle contractile function to then decline at an attenuated rate [173]. The sarcopenic process in the lower extremity is accelerated by disuse, disease and malnutrition which place women at greater risk of falling below the critical threshold of independence. As discussed in detail above, there is a differential loss in muscle mass in the upper and lower extremities and the reason for this not quite clear [11]. However, the significant decrease in physical activity (PA) at old age, even in fully independent older individuals, may be due alone to a more sedentary life style and resulting deconditioning [11]. Notably also, even the most trained master athlete shows an age-related decrease in maximal muscle strength, power, and rate of force development by increasing age caused by reductions in: myofiber numbers and CSA, MN firing frequency, agonist muscle activation, force steadiness and spinal circuitry function ([10]. However, replacing sedentary time with extended hours of physical activity seems to lead to a reduction in frailty associated with falls, disability and care [93, 177, 178] (Figure 7).

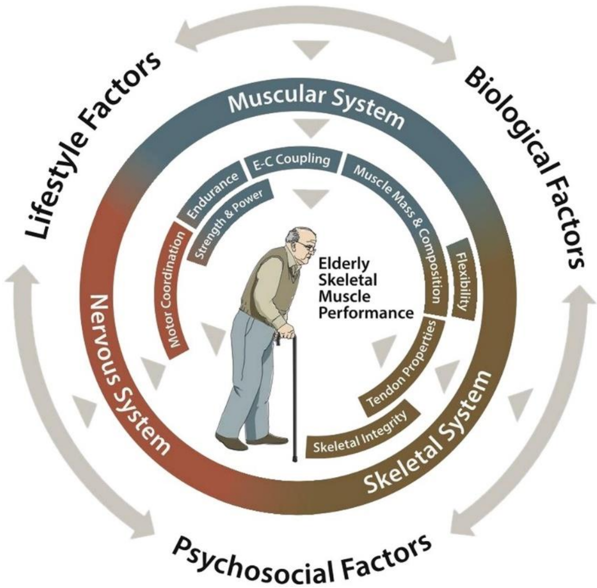

Figure 7. Diagram of the multifactorial determinants of elderly skeletal muscle performance. With permission from Tieland et al. 2018 [3].

1.6. Quality of life and ageing

Health related quality of life (HRQOL) is defined as "the value assigned to the duration of life as modified by the impairments, functional states and social opportunities that are influenced by disease, injury, treatment or policy"[179]. Chronic disease and bodily limitations are health problems that have been linked to reduced HRQOL [180]. Impaired functional performance with increasing age often results in a concurrent loss of independency and a decrease in self-perceived well-being [3] (Figure 7). Physical activity (PA) is an important factor to sustain a healthy lifestyle, while also contributing to uphold overall health, physical and cognitive function and cardiovascular health [181]. It seems that individuals who expect to maintain their physical and mental level with ageing also are more likely to participate in health promoting behaviors [182]. Seemingly, the level of confidence or "self-efficacy" of an individual influence his/her ability to complete a given task at hand, which has to be recognized as an essential component of well-being [183]. Noro and Aro (1996) described "quality of life" in a broad context of human experiences ranging from the necessities in life, such as food and shelter, to those of fulfilment and happiness [179]. Maintaining quality of life and the ability to sustain an independent lifestyle often are more important than a prolonged life expectancy [184, 185]. In addition, it is widely recognized that physical function is a key component in evaluation of health and well-being in the ageing population [183].

2. Aims

2.1. Overall aim

The aim of this dissertation is (I) to describe muscle function in women and men, (II) study the relationship between muscle function and functional capacity, (III) present reference values for selected measures of muscle function in elderly and address its relationship to health related quality of life scores, (IV) study the effect of immobilization and re-training on muscle power and postural control, and finally (V) to study maximum horizontal gait speed in chronic stroke sufferers compared to age-matched community dwelling elderly.

2.2. Specific aims

Study I

The aim of Study I was to investigate the influence of ageing and gender on the magnitude of maximal SSC muscle power production during coupled eccentric–concentric muscle contractions and concurrent force-velocity properties across the full adult age range.

Study II

The aim of Study II was to investigate lower limb mechanical muscle function (strength, power) and functional capacity in sub-groups of females and males aged 65–81 years to address the role of muscle power in the expression of functional capacity in the various stages of ageing.

Study III

The aim of Study III was to determine relevant reference values for various clinical tests of muscle function relating to older adults and to investigate the relationship with health-related quality of life.

Study IV

The aim of Study IV was to investigate the effect of 14 days lower limb immobilization and subsequent retraining on mechanical muscle function, postural control, and functional capacity in old and young men.

Study V

The aim of Study V was to investigate habitual (self-chosen) and maximum gait speed in individuals with mild to moderate disability in the chronic phase of stroke compared with similar data obtained in a community-dwelling elderly population.

3. Material and methods

3.1. Study setting and design

Studies I, II and III are cross-sectional uncontrolled observational studies in which the participants visited the research facility on a single occasion for the physical performance tests. Study IV is a llongitudinal controlled intervention study where the subjects visited the research lab four times, familiarization trails, pre-intervention of immobilization, post-immobilization and post re-training. After baseline tests, the subjects were subjected to unilateral limb casting from the hip to the ankle with a 30-degree flexion of the knee (0° = full extension). After two weeks of immobilization, and again after four weeks of training (progressive resistance exercise) the test protocol was repeated. All tests were performed in both limbs where the non-immobilized leg served as the within-subject control. Study V is a cross-sectional observational controlled study where both subjects and controls were tested at a single time point.

Table 1. Cohort of the five studies included in the thesis.

	Participants included	Study design	Measurement timepoints
Study I	315	Cross-sectional observational study	One measure point
Study II	154	Cross-sectional observational study	One measure point
Study III	192	Cross-sectional observational study	One measure point
Study IV	21	Longitudinal controlled intervention study	Three measure points, before and after intervention and after re-training intervention
Study V	258	Cross-sectional observational controlled study	One measure point before intervention.

3.2. Subject recruitment

This Thesis consists of five papers (Study I-V). In study I, II, III and controls in study V persons aged 65-81 years were part of the same cohort (Table 1).

Study I

The first study is a multicentre study where participants, depending on age, were recruited by different means of approach. In total, 315 persons participated. One hundred and thirty-five persons aged 18 years and older were recruited at the local university campus and 131 (42%) met the inclusion criteria. In collaboration with Odense, Denmark women and men aged 35–55 years were randomly selected through the National Civil Registration System as a matched control group for another study and met the inclusion criterion n=30 (9%) [186]. Nine hundred subjects aged 65-80 years residing in the Gothenburg municipality were randomly selected from the Swedish National Register and were invited by mail to take part in the study. Five hundred subjects accepted the invitation and were then contacted by a research nurse who conducted the first screening by phone. A total of 154 persons (65-80 yrs) fulfilled the criteria for Study I and were able to participate in the study (49%).

Study II

In Study II the same cohort of 154 persons from study I aged 65 – 80 years were included.

Study III

In Study III the same subjects aged 65-80 years volunteering for study I and II were initially invited. Of the 500 who accepted the invitation, 192 persons passed the screening and were able to participate in study III.

Study IV

In Study IV 20 healthy men, 9 old and 11 young volunteered to participate in the study. Prior to start of the study, all participants underwent a thorough medical examination by a physician, including a personal interview regarding drug use and measurement of blood pressure to screen for pathological conditions that could be exacerbated by the immobilization intervention.

Study V

In Study V a stroke cohort of 104 persons was recruited from the waiting list of Neuro Optima Forsk Rehab AB's rehabilitation programs. Permission was given to contact individuals who had applied to participate in the rehabilitation program. The control group of 154 community dwelling elderly individuals aged between 65 and 81 years was extracted from the same cohort as examined in studies I, II and III.

3.2.1. Subjects

Table 2. Number of subjects included in each study cohort.

Characteristics	Study I	Study II	Study III	Study IV	Study IV
Participants	315	154	192	20 Old / Young	258 Stroke/ Control
Women n (%)	188 (60)	81 (53)	105 (55)		39/ 81 (15/ 31)
Men n (%)	127 (40)	73 (47)	87 (54)	9/ 11 (52/ 43)	65/ 73 (25/ 29)

In Studies I and II subjects with severe chronic disease or disability were excluded subjects as well exposed to previous arthroplastic surgery or other types of severe injury in the lower extremity. In Study III the same exclusion criterion was applied as in Study I and II with the exception of allowing for injury or arthroplastic surgery in the lower extremity and being able to jump. The exclusion criterions in Study IV were cardiovascular disease, diabetes, neural- or musculoskeletal disease, inflammatory or pulmonary disorders, and any known predisposition to deep venous thrombosis, which was screened by a trained physician. Physical activity during work and leisure was moderate and no previous participation in strength training. The criterion for inclusion in study V for the stroke cohort was a minimum of 6 months and a maximum of 10 years since stroke with a disability grade 2-4 on the modified Rankin scale together with a less than full score on the primary outcome measure

(M-MAS UAS) [187, 188]. No other injury, illness or addiction was allowed as well as the ability fully understand instructions were also part of the inclusions.

3.3. Test procedures

3.4. Muscle power

3.4.1. Maximal SSC muscle power (Study I & II)

The force plate analysis not only provides the maximal vertical height of the countermovement jump (CMJ), but quantifies the vertical power exerted on the body center of gravity (BCG) during the eccentric (ep) and concentric phases (cp) of the take-off. The force plate analysis provides direct measures of the two principal power components, namely vertical ground reaction force (Fz) and BCG velocity continuously throughout the jump. The force plate is widely used both in clinical practise and research and has shown to be a valid and reliable measuring tool [108, 127, 189, 190].

Specifically, vertical ground reaction force *(Fz)* was measured (1000 Hz) during standardized CMJ manoeuvres by means of an instrumented force plate (AMTI OR6-5-1, Watertown, MA 51 x 46 x 8 cm and Kistler 9281 B, Winterthur, Switzerland) (Figure 8) [120]). The *Fz* signal is analyzed according to the methods of Davis and Rennie (1968) and Caserotti et al. (2001) where the vertical velocity *(V)* of the body centre of gravity *(BCG)* is determined by time integration of the instantaneous acceleration signal ($\int([Fz/m]-g)\,dt$, where m = body mass, g = 9.81 m/s²). Thereafter, the vertical position of the centre of mass *(CMpos)* was obtained by time integration of the velocity signal ($\int V\,dt$). Throughout the entire movement, instantaneous power exerted on the BCG is calculated as the product of vertical ground reaction force *(F)* and BCM velocity *(V)* [2, 120, 128].

The jumps can then be analyzed both in the eccentric (Ecc) and concentric (Con) phase. In other words, movement of BCG in the downward phase, negative velocity, and upward propulsive phase, positive velocity. Each CMJ was analyzed for maximal jump height (JH) based on the vertical velocity of BCG at the instant of take-off (JH = $V^2_{take\text{-}off}/2g$). The propulsive take-off phase and its duration (T-Con) also was determined, while peak vertical force was identified in the eccentric movement phase (Fpeak-Ecc) and the concentric phase (Fpeak-Con), respectively. BCG peak power (Ppeak) was identified in the concentric phase together with its integral components, vertical velocity (VPpeak) and vertical ground reaction force (FPpeak) at the instant of Ppeak. In the concentric phase the total work produced on BCM (Work-Con) was determined as this determines JH. Finally, the rate of vertical force development *(RFD= dFz/dt)* was calculated in the first 100 ms of the eccentric deceleration phase (Fz ≥ bodymass) in order to evaluate the kinetic quality of the ballistic jumping movement.

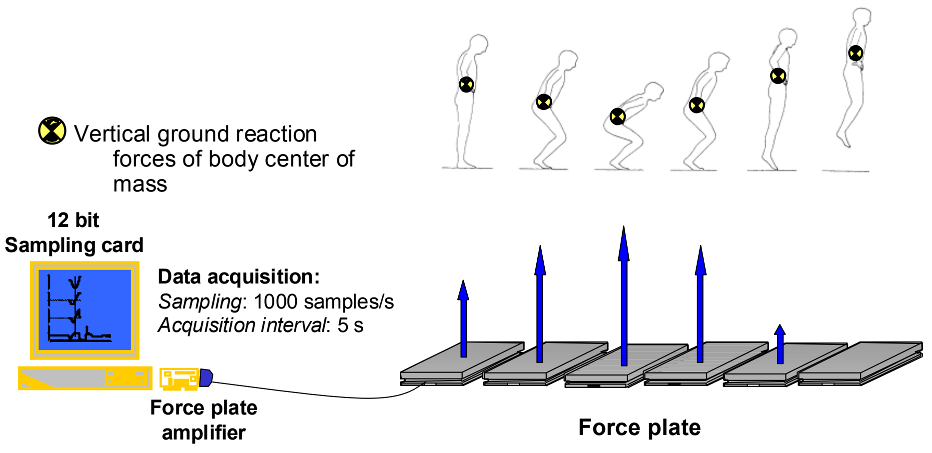

Figure 8. Force plate recording used to measure Stretch-shortening cycle (SSC) muscle power of the leg extensors during maximal CMJ testing. Courtesy of Casserotti, Aagaard et al, J Eur J Appl Physiol 2001 [120].

Starting from an upright standing position, the subjects were instructed to perform a fast downward movement to about 90° knee flexion to be immediately followed by a fast upward movement, and to jump as high as possible. To minimize the influence of the arms the subjects were instructed to keep their hands on their hips [110, 191]. The jump was visually demonstrated to the subject who subsequently perform three sub maximal trail jumps. After a short rest the subject preformed three maximal jumps with 1-minute rest in-between. The jump with the highest jump height (cm) was selected for further analysis. The vertical force signal (Fz) was analyzed using custom made analysis software programmed (Aagaard P) in Biomax (Simonsen EB) (Figure 9).

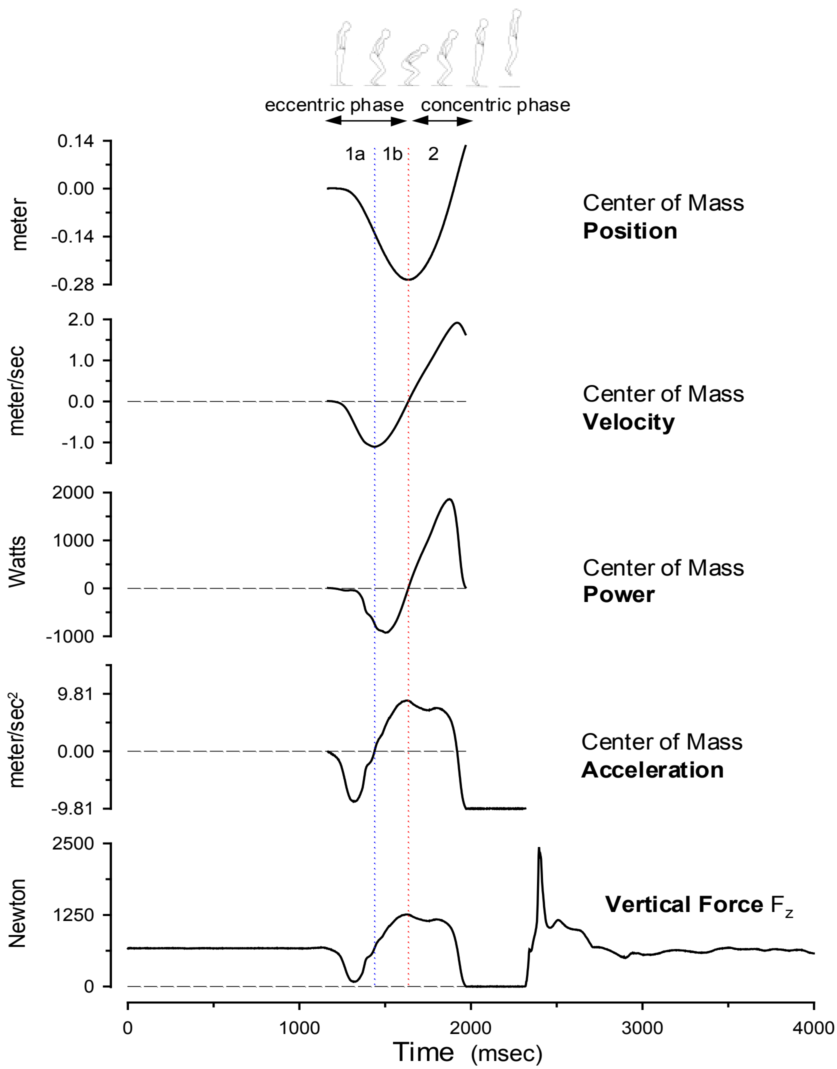

Figure 9. A representative counter-movement jump divided into eccentric and concentric phase, showing peak velocity of the body center of mass, as well as peak power and peak force. With permission Caserotti & Aagaard (2001) [120].

3.4.2. Nottingham power rig (Study IV)

In study IV maximal unilateral leg extension power (LEP) was evaluated using the Nottingham Power Rig [192]. All values were expressed in Watts (W) normalized to body weight (W/kg). The subjects were seated, and the horizontal position of the seat was adjusted to allow a knee angle of 15° with the footplate being fully pushed down. To ensure the same seat setting across test sessions, the seat position was measured to the nearest millimeter and recorded. The subjects' arms were folded over the chest and the upper body leaning slightly backwards. The foot that was tested was placed on a pedal attached to the flywheel while the other foot rested on the floor (Figure 10). Two to three warm-up trials were followed by the data sampling. Verbal instructions were standardized, and the participants were instructed to push the pedal forward as hard and fast as possible. This was repeated until no further improvements in peak power of two consecutive tests could be observed, using a minimum of five trails. Between each test a rest period of 30 sec was obligatory. The order of the test leg was randomized. Measurement of maximal muscle power using the Nottingham Power Rig has previously been validated and considered to be safe in old and very old individuals [193].

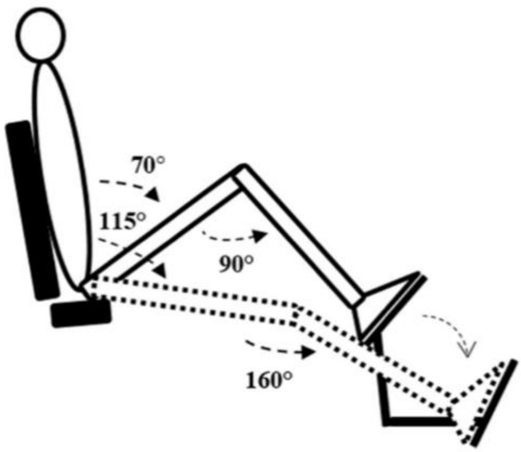

Figure 10. Nottingham power rig used to measure maximal unilateral leg extensor power. With permission from Van Driessche et al. 2018 [194].

3.5. Muscle strength

3.5.1. *Leg extension MVC (Study II & III)*

Maximal voluntary isometric knee-extension (MVC) force (N) was measured bilaterally with a stabilized portable dynamometer (Steve Strong®, Stig Starke HB, Göteborg & Växjö, Sweden). By using a modified quadriceps table, the dynamometers strain gauge was attached to a strap and ankle cuff. The digital display shows the magnitude of peak force (expressed in N) exerted on the dynamometer load cell. The subject was seated with approximately 90° hip flexion, and the thighs fully supported, and with the lower leg pointing perpendicular to the floor in approximately 90° knee flexion (Figure 11). A non-elastic (i.e., highly stiff) strap connected to the dynamometer ran horizontally across the floor and was placed around the subject's ankle with the lower part of the cuff on the proximal lateral malleolus. A small backrest supported the subjects lower back and thighs were strapped down with a Velcro® belt. Arms were crossed over the chest when performing the isometric MVC contractions, each performed for a 5- second time period verified with a digital stopwatch. Three trials were recorded in each leg and the highest value was selected for further analysis. This method has been used in other clinical studies and has shown high test-retest reliability in unpublished data [195, 196].

Figure 11. Stabilized isometric dynamometer (Steve Strong) used to assess maximal voluntary isometric knee-extensor (MVC) force.

3.5.2. Hand Grip strength MVC (Study II & III)

Maximal handgrip strength was assessed with the Grippit® dynamometer (AB Detector, Gothenburg, Sweden) an electronic instrument which records both maximum and average (10 s) grip strength values (Figure 12). The Grippit® is a portable, electronic instrument with a grip device and arm support that enables standardized arm and grip positioning. The device is mounted on a portable base on a hight adjustable table. The subjects were seated in a hight adjustable chair without armrest close as possible to a 90◦ hip flexion with feet firmly planted on the floor. The elbow was resting in the arm support at a 90◦ angle with the hand in a neutral position. The force exerted against the transducer in the grip cylinder is recorded and displayed digitally. Three trials were performed on each hand always starting with the right hand. The time between each trial is approximately 30 s. The sampling of data is during a 10 s of an MVC. The highest MVC value of each hand was used for analysis. As suggested in previous studies a standard size cylindrical grip, measuring 45 mm in depth and 27 mm in with, was used for all the subjects [197, 198]. The Grippit® has shown excellent reliability [199].

Figure 12. Assessment of maximal hand grip strength.

3.6. Functional performance

3.6.1. Sit to Stand Test (Study IV)

The Sit-to-Stand Test (STS) is also known as the 30 s Chair Stand Test and is an outcome measure for combined lower limb mobility, strength and endurance [200]. The test measures the number of times a person is able to rise and sit from a standardized chair with in: (i) 30 s and (ii) 5-Times Sit-to-Stand Test (5-TimeSTS) measures the time it take for a person to rise and sit from a standardized chair five times [200-202]. In both tests, the participant was seated on a standardized chair (45 cm) without armrest, straight back and arms crosse over the chest. At a given signal the participants were instructed to stand up to a full erect and straight position and then immediately return to the initial seated position. During the STS the participants were instructed to complete as many full stands as possible with in the 30 s, and the total number of stands with in the time period was measured [202]. During the 5-Time STS the time it took to rise five times was measured to the nearest second [201].

3.6.2. Heel-rise test (Study II & III)

In study II and III lower leg muscle endurance was assessed by means of the unilateral heel rise test (*HR*) [203]. The subject is standing on a 10° tilted wedge on one foot using standardized footwear. A wall mounted measure stick was set to mark height of movement by ways of a heel rise performed with two feet. By lightly touching the wall with the fingertips at shoulder level postural balance is supported (Figure 13). To standardize speed of movement during the test a metronome marked cadence of the movement (60 bpm) that corresponded to a mean ankle angular velocity of approximately 60 °/s, while the knee was kept straight. Familiarization of the procedure started with the left foot, but the actual test always started with the right foot. The subject was instructed to lift the heel as high as possible at the pre-set frequency until no further heel-rises could be performed (cadence failed to be sustained). Subsequently, the procedure was repeated with the left foot. One trial per foot was conducted and number of heel rises was counted and registered for each leg.

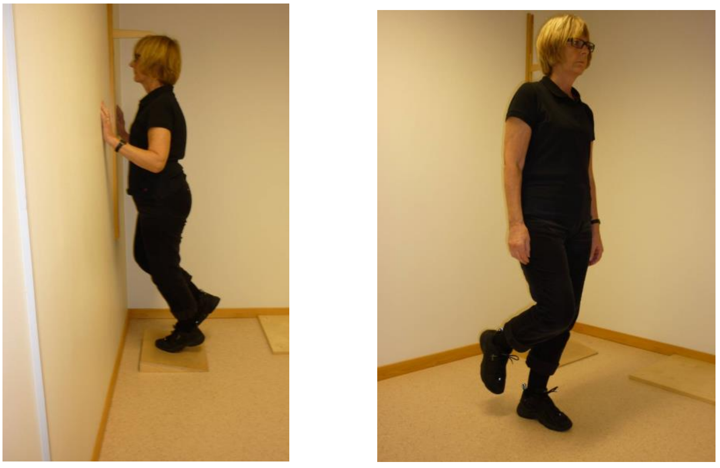

Figure 13. Heel-rise test (HRT) and postural control (SOLEO) (Study II and III.

3.6.3. 2-minute Step Test (Study IV)

Muscle endurance in the lower limb was measured using the 2 minute step test (2MST) [204]. The test is part of the Senior Fitness Test and normative data have been presented with comparable results between aged-matched populations [205, 206]. In upright position the test subject stands next to a wall, a mark is place on the wall corresponding to midway between the patella and the iliac crest. On a given signal the subject begins stepping in the place for 2 minutes, raising each knee to the mark on the wall for as many times as possible. In the present study, a modified version where the number of times of both knees hit the mark during the 2 minuets was used instead of the right knee only.

3.6.4. Timed-up and Go (Studies II & III)

Dynamic mobility, balance and agility were assessed using the Timed Up and Go Test (TUG) [207]. The TUG measures the time it takes a subject to stand up from an armchair, walk 3 m, turn, walk back to the chair, and sit down. On the floor, the distance of 3 m was marked, and the participants were seated in an armchair of standard height. Standardized instructions were given to the participants to walk the marked distance at their normal speed, cross the line before turning around, walk back to sit down in the chair again. The timing of the TUG started when the participant's back rose from the chair. The participants performed three trials, and the fastest trial measured in seconds was registered.

3.7. Postural control

3.7.1. Balance tests (Studies II & III)

The ability to maintain postural balance (PB) on one leg was evaluated with a single-leg stance test measured as the time that the participant could stand on their self-selected best foot without hand support with their eyes open (Figure 13) [208]. The subjects were instructed to stand on their preferred leg within a designated floor area (50 cm Ø circle) with eyes open and no hand support. The contralateral foot was not allowed to touch the floor (toes positioned at the level of the medial malleolus of the standing leg) and no contact between legs was allowed. Arms were allowed to move freely for balance. The end of test was defined as touching the ground with their contralateral foot and measured in seconds with a digital stopwatch. The maximum score was 30 s, after which time the test was stopped.

3.7.2. *Sway on force plate (Study IV)*

An instrumented force plate (AMTI OR6-5-1000, 40 x 60 cm; Advanced Mechanical Technology Inc., MA, USA) was used to measure postural sway during static bilateral stance. Vertical ground reaction force *(Fz)* and force moments *(Mx, My)* signals from the force plate were synchronously sampled using an external 12-bit A/D converter (dt2801, Data Translation) at 100 Hz sampling rate. During later off-line analysis all force plate signals were lowpass filtered using a 4^{th} order zero-lag Butterworth filter with a cutoff frequency of 8 Hz [209] , following which the horizontal (x,y) trajectory of the center of Pressure *(CoP)* was calculated using customized software (Aagaard P) as $x = x_o + My/Fz$, $y = y_o + Mx/Fz$, with $[x_o, y_o]$ representing the geometrical center of the force plate surface. CoP sway velocity $(mm \cdot min^{-1})$ and total CoP sway area (mm^2) were also calculated [210]. In each data sweep the participant was instructed to stand as still as possible for 15 seconds. Two different types of tests were executed; 1) with eyes open, arms freely hanging and feet placed together (double-leg stance) in a Romberg test position; 2) eyes open and single-leg stance test without hand support [204, 211]. To ensure a consistent visual focus, a black circle (10 cm Ø) was placed in front of the participant at eye level 2.5 m away. Prior to each test session the participants performed a few practice trials. Data sampling was initiated once the participants had settled in a safe and stable position CoP sway length and sway area during the two tests were identified from the trials with the shortest sway length and used for analyses.

3.8. Gait speed

3.8.1. *30 m Walk Test (Study II & III)*

In study II and IV habitual and maximal horizontal gait speed were assessed with the 30 m walk test (30mWT) executed in a quite corridor [212]. From a standing position behind a mark on the floor the participants walked the distance. Timing started and stopped once the first foot passed the mark of the distance in the beginning and the end of the corridor. The first trail was measured at the participants self-selected speed (30mWT-self) and the second trail were maximal walking speed

(30mWT-max) without running. Through the walk the examiner walked discreetly behind the subject with a digital stopwatch. The time for each trial was recorded in seconds with a stopwatch and mean 30 m gait speed was calculated and expressed in meters per second (m/s).

3.8.2. 10-m Walk Test (Study IV & V)

The 10-m Walk Test is a performance measure used to assess habitual and maximal horizontal walking speed over a short distance. The test can be employed to determine functional mobility, gait, and vestibular function. Habitual and maximal gait speed (GS) were measured over a 10-m straight walking course [213]. The participants were asked to walk 10 m at their habitual speed (best of 2 trials) followed by walking 10 m at their maximal walking speed (best of 2 trials). This was done without running and with participants instructed to continue to walk past the 10 m mark to avoid deceleration before reaching the 10 m mark [213, 214]. The time was measured with a digital stopwatch to the nearest 0.1 s and no verbal encouragement was given. GS (maximal and habitual) was computed as the 10-m distance divided by the elapsed time, hence expressed in m/s.

3.9. Questionnaire

3.9.1. Health related quality of life – SF-36 (Study III)

Through a questionnaire health related quality of life (HRQL) was evaluated by the Medical Outcomes Study 36-Item Short Form Health Survey - SF-36. Two domains, physical (PCS) and mental health (MCS) are considered the major subgroups in SF-36. In each subgroup four health related concepts were measured. The PCS scores included measurements of physical function (PF), role-physical (RP), bodily pain (BP), and general health (GH). MCS scores included measurements of vitality (VT), social functioning (SF), role emotional (RE) and mental health (MH). The higher the SF-36 score, the greater the HRQOL [215-218].

3.10. Intervention (Study IV)

3.10.1. Immobilization

By randomization a single leg was immobilized with a cast from the groin to the ankle (~30° knee angle, 0° = full extension). Full mobility was possible for the hip and ankle joint, respectively, which resulted in selective unloading in the knee extensor muscles. The biarticulate knee flexors (biceps femoris caput longum and semitendinosus, semimembranosus muscles) could be activated during hip extension, which was not restricted. Equipped with crutches the participants were instructed not to perform any weight bearing activities with the immobilized leg. Free ambulation using the non-immobilized leg was allowed during the 2 weeks of immobilization with participants carefully instructed to abstain from ground contact and isometric contractions in the immobilized leg. On a regular basis the subjects were contacted and instructed to maintain the venous pump exercise around the ankle joint several times per day to prevent potential thrombosis. To ensure full range of knee joint motion and to avoid pain, the participants received manual physiotherapy in the immobilized leg immediately after removal of the cast prior to testing.

3.10.2. Retraining

Following immobilization all study participants underwent supervised retraining for 4 weeks (3 times per week) involving progressive unilateral resistance exercise (Train) targeting the immobilized leg only. Workouts always started with a short warm-up on a stationary ergometer bike. Three exercises (leg press, knee flexion, knee extension) were executed during each session. The initial training load was estimated using a 5-repetion maximum (RM) test and loads were adjusted weekly [219]. The first week of retraining consisted of 4 sets of 12 repetitions at 15 RM loading intensity. The second and third weeks consisted of 5 sets of 10 repetitions using 12 RM loads and finally, the fourth week consisted of 4 sets of 10 repetitions at 12 RM load intensity.

3.11. Statistical analysis

3.11.1 Reliability and validity of outcome measures

Intra class correlation coefficient (ICC) describes how strongly units in the group resembles each other. It can be used in quantitative measurement and descriptive statistics. Acceptable-to-high reliability and validity have been reported previously for the outcome variables obtained in the present series of studies (Table 3). Based on the 95% confident interval (CI) the estimate of ICC indicate poor (<0.5), moderate (0.5-0.75), good (0.9) and excellent (>0.9) reliability, respectively [220].

Study I

Study I employed a single time point of measurements, with subjects divided into three age-groups Young 18 – 34 years, Middle aged 35 – 55 years and Old 65 – 81 years and further split into males and females. To compare the difference of means between women and men within their respective age-groups an independent t-testing was used to determine significance between the two groups. To explore the impact of age on selected parameters a one-way between-groups analysis of variance with post-hoc using Tukey test was performed. To obtain the age effect on the CMJ parameters the Pearson product-moment method was used for regression analysis. To obtain normalized decline rates in % per year a regression analysis on normalized data was performed using the mean values at 20 years of age as a reference value (= 100%). To examine whether specific age-related decline rates differed between genders, difference in regression slopes were analyzed by comparison of 95% confidence intervals.

Study II

Study II also employed a single measure point, and the subjects were divided into three age-groups; Young old 65 – 70 years, Old 71 – 75 years and Oldest-old 76 – 81 years and split into groups of sex. All continues variable were described with group means and standard divinations. Sex difference within their age group was evaluated by the unpaired independent t-test. By two-way analysis of variance (ANOVA) SSC Ppeak and parameters for mechanical muscle function and functional capacity age-groups were compared. Further post hoc analyses with Tukey's were made for comparison of age groups. In order to evaluate age effect on SSC Ppeak and the other outcome measures univariate linear regression analyses were performed. This was also done to evaluate the relationship between SSC Ppeak and the other outcome measures. Correlational effects were examined by plotting outcome parameters against explanatory variables by assumption. For descriptive purposes beta-coefficients with 95% confidence intervals (CIs) were extracted using linear regression analysis, this to quantify the change in outcome variable by a 1-unit increase in the explanatory variable, together with the associated p-value and r^2 (coefficient of determination or explained amount of variance).

Study III

In study III data were collected on two different occasions and the subjects were divided into groups of sex. All continues variable were described with group means and standard divinations. Sex difference was evaluated using unpaired independent t-testing. SF-36 and physical function parameters were compared between subject groups using one-way analysis of variance (ANOVA).

Study IV

Study IV comprised two subject groups, young men (YM, 24.4 ± 1.6 years) and old men (OM, 67.3 ± 4.4 yrs), who were assessed at three separate time points (*Pre, Imm, Train)*, and paired t-tests were used to evaluate within-group changes between these time points. An analysis of covariance (ANCOVA) was used to evaluate differences between YM and OM for each outcome parameter across the three timepoints. Potential associations between longitudinal changes in selected outcome measures based on relative changes (%) were assessed using the Pearson product-moment method (presented as r-value and p-value) and linear regression analysis (indicating the specific linear relationship (slope, intercept) between the related variables. Potential relationships between maximal muscle power and other relevant outcome measures were determined by means of Pearson correlation analysis.

Study V

In Study V it was investigated if maximum gait speed was dependent on comfortable habitual gait speed in a group of individuals with a history of stroke and compared to a group of age-matched community dwelling healthy elderly individuals. Correlations between two continuous variables were established using Spearman's Rho analysis while differences between two subject groups were evaluated using the Fisher's r to z transformation. The influence of gender on gait speed was analyzed with the Mann-Whitney U-test and the potential relationships between categorical data and gait speed were evaluated using the Jonckheere-Terpstra test. Independent samples t-test was used for comparison of gait speeds between groups. All variables significant at 0.10 level were included in a stepwise linear regression analysis.

Table 3. An overview of reliability and validity studies examining the present outcome measures.

Test		Study	ICC
Counter-movement jump (CMJ)	*cm*	Slinde F et al. *Test-retest reliability of three different countermovement jumping tests* J Strength Cond Res 2008 Vol. 22 Issue 2 Pages 640-4	0.93
Nottingham Power Rig (LEP)	*W/kg*	Bassey & Short *A new method for measuring power output in a single leg extension: feasibility, reliability, and validity* Eur J Appl Physiol Occup Physiol 1990 Vol. 60 Issue 5 Pages 385-90	0.80
Force plate sway (PB)	*mm^2*	Quatman-Yates et al. *Test-retest consistency of a postural sway assessment protocol for adolescent athletes measured with a force plate* International journal of sports physical therapy 2013 Vol. 8 Issue 6 Pages 741	0.90
Stig Starke (MVC)	*N*	Wedin M. *A study of reliability measuring maximal isometric strength in knee extensor with a specific apparatus- Steve Strong Unpublished Bacholors thesis, University of Gothenburg 2002*	
Gripp-it (MVC)	*N*	Svanesson U et al. *A comparative study of the Jamar® and the Grippit® for measuring handgrip strength in clinical practice* Isokinetics and Exercise Science 2009 Vol. 17 Issue 2 Pages 85-91	0.93
Heel rise test (HRT)	*n*	Cider Å et al. *Reliablity of clinical muscular endurance tests in patiens with chronic heart failure* Eur J Cardivasc Nurs. 2006 Jun;5(2):122-6.	0.93
Physical functional performance		Sherrington C, Lord RS *Reliability of simple portable tests of physical performance in older people after hip fracture* Clin Rehabil 2005 19:496	0.75
Timed-up and Go	*sec*	Steffen et al. *Age- and gender-related test performance in community-dwelling elderly people: Six-Minute Walk Test, Berg Balance Scale, Timed Up & Go Test, and gait speeds Phys* Ther 2002 Vol. 82 Issue 2 Pages 128-37	0.97
Gait speed (30mWT-self/max	*m/s*	Andersson M et al. *Measuring Walking speed in COPD: test-retest reliability of the 30-meter walk test and comparison with the 6-minute walk test* Prim Care Respir J 2011;20(4): 434-440	0.87/ 0.93
10 m maximal walking speed (GS)	*m/s*	Adell et al. *The Test-Retest Reliability of 10 Meters Maximal Walking Speed in Older People Living in a Residential Care Unit* Journal of geriatric physical therapy 2013 Vol. 36 Issue 2 Pages 74-77	0.86
5-time sit-to stand (5-STS)	*sec*	Bohannon RW *Test-retest reliability of the five-repetition sit-to-stand test: a systematic review of the literature involving adults* The Journal of Strength & Conditioning Research 2011 Vol. 25 Issue 11 Pages 3205-3207	0.81
Step performance (2MST)	*n*	Sherrington C, Lord RS *Reliability of simple portable tests of physical performance in older people after hip fracture* Clin Rehabil 2005 19:496	0.92
Health-related quality of life (SF-36)		Sullivan et al. The Swedish SF-36 Health Survey--I. Evaluation of data quality, scaling assumptions, reliability and construct validity across general populations in Sweden Soc Sci Med 1995 Vol. 41 Issue 10 Pages 1349-58	0.90

4. Results

4.1. Study I

Stretch-shortening cycle muscle power in women and men aged 18–81 years: Influence of age and gender

The below list summarizes the findings in Study I that investigated the influence of aging and gender on the magnitude of maximal SSC muscle power (SSC Ppeak) production during coupled eccentric–concentric muscle contractions among 315 subjects aged 18 – 81 years.

- SSC Ppeak is greater in men than in women throughout the full-adult life span.
- Men showed a ~50% grater aged-related decline in SSC Ppeak (W/kg/year) than women in the ages 18 – 81 years with an annual rate of 0.44 and 0.29 W/kg respectively ($P<0.001$).
- Increase in age explained the decline in Ppeak by 68% and 74% (r2) in women and men respectively.
- One of the bimodal components of Ppeak, FPpeak, declined at a greater annual rate in men than in women, 0.07 and 0.04 N/kg respectively ($P < 0.001$).
- The other bimodal component of Ppeak, VPpeak, declined at a greater rate in men then in women, 0.02 and 0.01 m/s respectively ($P= 0 .002$).
- In FPpeak age was the strongest explanatory factor by 22% for women and 46% for men (R^2).
- In VPpeak age explained 74% and 68% in women and men respectively (R^2).
- The progressive greater decline in maximal SSC power result in a convergence between genders at old age.
- Compared to age-matched men, women in the two older groups showed higher RFD (< 0.05).
- With an annual decline rate of -0.79 and -0.88 Nm/s on RFD ageing had a negative effect on women and men respectively.
- Approximately 20% of the decline in RFD could be explained by aging in both women and men.
- The magnitude of vertical displacement of BCM during the jump decreased at a similar rate with ageing for both women and men.
- Decline in the downward BCM displacement (ds-Ecc) was greater than that of the upward BCM displacement (ds-Con).
- The duration for T-Con was unaffected by ageing.

- The older subjects moved their BCM a shorter distance, hence reflecting that the older subjects moved their BCM at a slower speed.
- In the Fpeak-Ecc it seems that older women were better at transferring the generated force into the following concentric phase Fpeak-Con of the movement.

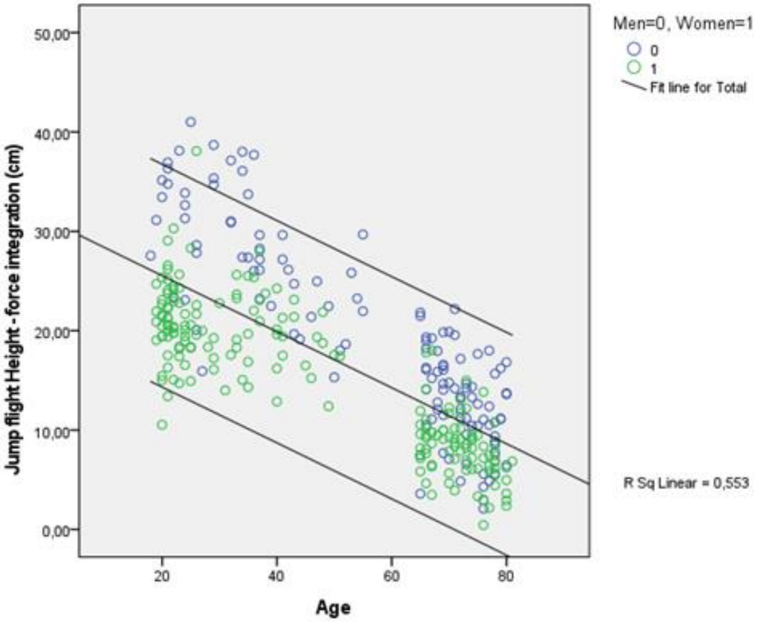

Figure 14. Age-related development in jump height (JH) in centimeters at Ppeak separated for women (n = 188, green) and men (n = 127, blue). Decline rates (regression slopes) differed between genders ($P < 0.05$) Dotted lines: ±SD.

In conclusion, we could for the first time present that maximal Stretch-shortening cycle leg extension power (SSC Ppeak) is greater in men than in women throughout the adult life span. However, it declines at a greater rate in men than in women which results in a convergence between women and men at old age in regard to maximal SSC power production.

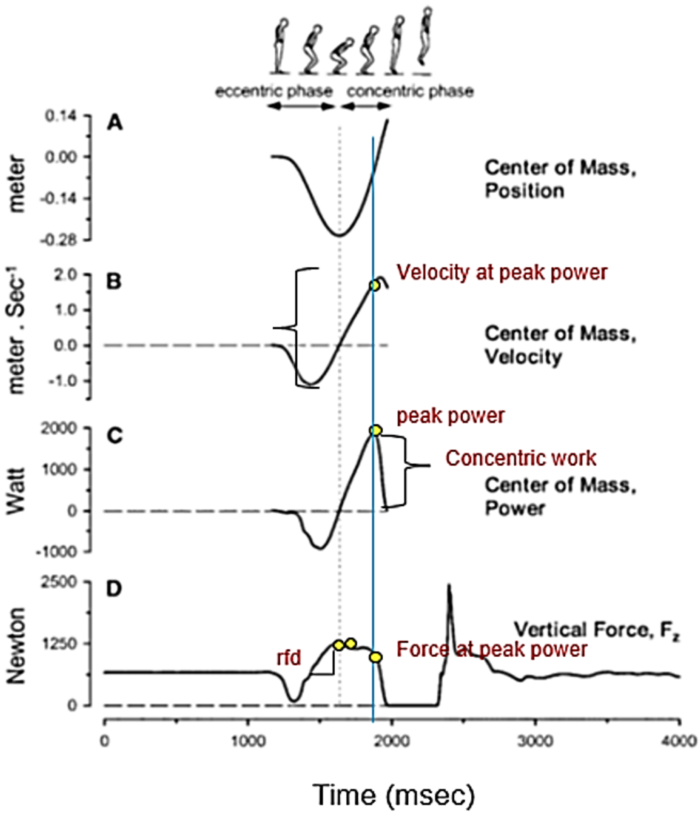

Figure 15. A representative counter-movement jump divided into eccentric and concentric phase, showing peak velocity, peak power and peak force. With permission applied from Aagaard P et al 2001 [120].

4.2. Study II

The effects of ageing on functional capacity and stretch-shortening cycle muscle power

The below list presents the results of Study II that examined the effects of age and gender in an ageing population with respect to functional decline and the relationship between muscle power and functional performance. This descriptive and explorative study enrolled 154 community-dwelling females and males aged 65-81 yrs.

- For all age groups examined SSC Ppeak and JH were higher in males than in females ($p<0.001$-0.05) (Table4).
- In all three age groups males generated higher maximal muscle strength (MVC, Grip) compared to women ($p<0.001$-0.01).
- In all three age groups females performed similarly to men in HRT, PB, TUG and 30mWT ($p<0.001$).
- However, in the youngest-old age group men outperformed women in 30mWT-max ($p<0.001$).
- There was an overall trend towards an age-related decline in functional performance for both males and females (Table 4).
- Age accounted for 10-15% of the variance in SSC Ppeak, PB, TUG and 30mWT.
- Age accounted for 10% of the variance in JH, MVC, Grip and HRT.
- In comparisons between age groups, middle-old individuals performed significantly poorer compared to youngest-old in left-handed grip strength for females and maximum gait speed for males (Table 4).
- In a majority of the outcome measures oldest-old males demonstrated lower values than youngest- and middle-old males ($p<0.01$–0.05) (Table 4).
- In a majority of the outcome measures oldest-old females demonstrated lower values than youngest- and middle-old females ($p<0.05$) (Table 4).
- SSC Ppeak was 5.9% lower in the middle-old compared to the youngest-old men (27.3 vs 29.0 W/kg; $p<0.001$).
- SSC Ppeak was 13.7% lower in the oldest-old compared to the middle-old men (27.3 vs. 23.5 W/kg; $p<0.05$).
- SSC Ppeak was 16% lower in the oldest-old compared to middle-old females (18.9 vs 22.5 W/kg; $p=0.004$).
- But no difference was observed in SSC Ppeak between middle-old and youngest-old females ($p=0.47$).
- SSC Ppeak explained 66–69% of the age-related variance in maximal vertical JH ($p<0.001$).
- SCC Ppeak explained 24 and 26% of the age-related variance in right- and left-sided maximal leg extension strength in the youngest-old, respectively ($p<0.001$).
- SSC Ppeak explained the age-related variance in leg extension to a greater degree in middle-old and oldest-old (37/40% and 33/40%, respectively).
- SSC Ppeak explained 27–38% of the age-related variance in grip strength to a similar degree in the different age groups.
- SSC Ppeak explained the age-related variance in HRT, PB and TUG but to a lesser degree (5-26%).
- In youngest-old and middle-old, SSC Ppeak did not significantly contribute to the variation in self-selected gait speed.

- SSC Ppeak explained horizontal gait speed to a lesser degree (16–19%) in the youngest-old and middle-old.
- SSC Ppeak explained 41 and 54% of the variance in self-selected and maximum gait speed for the oldest-old respectively.

In conclusion, the age-related decline in functional performance appears to be accelerating when approaching the 8th decade, during which maximal SSC muscle power of the lower limbs also seems to have a stronger impact on jump height, balance, and horizontal gait speed. This indicates that the implementation of exercise protocols to improve maximal muscle power is becoming increasingly important for adults approaching very old age (+75 years). It is suggested that jump height as a proxy of muscle power in combination with maximal horizontal gait speed provide a strong tool of pre-frailty in old adults (+75 yrs). These results also highlight the need for effective clinical diagnostic tools to assess skeletal muscle mass loss, impairment in muscle strength and reduced physical functional performance to facilitate early intervention to mitigate loss of functional performance in order to facilitate for people to maintain, or even improve, the quality of life at later stages of their lives.

Table 4. SSC muscle power, vertical countermovement jump height, isolated muscle strength and functional capacity split by age group and gender.

		65–70 years Male n=29 Female n=33	Gender diff	71–75 years Male n=20 Female n=26	Gender diff	76–81 years Male n=24 Female n=22	Gender diff	ANOVA	Univariate linear regression with age as independent variable		
Outcome	**Gender**	**Mean (95% CI)**	**p-value**	**Mean (95% CI)**	**p-value**	**Mean (95% CI)**	**p-value**	**p**	**R^2**	**Beta (95% CI)**	**p**
SSC P_{peak} (W/kg)	M	28.95 (4.41)	***	27.25 (5.47)	***	23.52 (5.14) †‡	**	***	.10	-.33 (-.54; -.21)	***
	F	23.65 (3.81)		22.53 (3.35)		18.92 (4.09) †‡		***			
JH (cm)	M	24.84 (5.46)	***	22.76 (4.78)	**	19.60 (6.00) †	*	**	.07	-.27 (-.51; -.14)	***
	F	19.15 (4.30)		18.54 (3.55)		16.09 (5.69) †		*			
MVC (R) (N)	M	460.38 (119.65)	***	414.20 (85.68)	***	355.54 (91.40) †	***	**	.05	-.23 (-9.54; -1.77)	**
	F	302.24 (88.70)		257.88 (81.92)		263.27 (69.75)					
MVC (L) (N)	M	466.69 (115.28)	***	438.05 (73.94)	***	331.33 (90.54) †	**	***	.07	-.26 (-10-63; -2.77)	***
	F	296.42 (81.93)		247.38 (81.88)		264.00 (68.79)					
Grip (R) (N)	M	417.55 (87.76)	***	431.30 (57.95)	***	368.33 (95.12) ‡	***	*	.01	-.11 (-6.57:1.26)	
	F	243.15 (57.60)		227.88 (53.84)		196.73 (49.33) †		*			
Grip (L) (N)	M	417.69 (74.12)	***	399.65 (55.89)	***	355.58 (94.29) †	***	*	.03	-.17 (-7.92; -.38)	*
	F	244.82 (47.88)		209.85 (48.60) ¥		176.82 (49.36) †		***			
HRT (R) (number)	M	12.93 (8.16)		11.45 (8.03)		7.75 (7.36)			.08	-.29 (-.74; -.23)	***
	F	12.06 (9.20)		8.15 (6.21)		5.77 (5.06) †		**			
HRT (L) (number)	M	12.76 (10.48)		8.55 (7.97)		6.00 (5.99) †		*	.07	-3.52 (-.73; -.20)	***
	F	10.7 (8.68)		7.42 (6.18)		6.45 (6.25)					
PB (sec)	M	27.10 (5.51)		25.30 (8.78)		20.21 (11.29) †		*	.14	-.38 (-1.03; -.47)	***
	F	28.24 (4.40)		23.08 (9.64)		17.86 (11.31) †		***			
TUG (sec)	M	7.38 (0.98)		7.65 (1.04)		8.83 (1.76) †		***	.11	.33 (.06:.16)	***
	F	7.39 (1.52)		7.77 (1.27)		8.86 (2.21) †		**			
30 m Self (m/s)	M	1.47 (0.15)		1.43 (0.13)		1.29 (0.20) †		***	.13	-.37 (-.02; -.01)	***
	F	1.47 (0.22)		1.38 (0.18)		1.28 (0.24) †		**			
30 m Max (m/s)	M	2.31 (0.39)	***	2.06 (0.22) ¥		1.87 (0.37) †		**	.15	-.40 (-.04; -.02)	***
	F	1.99 (0.27)		1.97 (0.29)		1.71 (0.30) †‡		***			

M=Men; W=Women; *SSC P_{Peak}*= Stretch-shortening cycle peak muscle power; *JH*=Jump Height; *MVC*=Maximum voluntary contraction; *Grip*=Grippit; *HRT*=Heel rise test; *PB* = Postural balance, time for sustained standing on one leg with eyes open; *TUG*=Timed-Up and Go; *30mWT*= 30-meter walk test; Self= Self-selected speed; Max= Maximum speed. Data is total mean value and standard deviation (SD) split by age group and gender. P-values show difference between men and women: p<0.05*, 0.01**, 0.001***. Statistically significant differences between age groups in men and woman: †: Age 65–70 vs Age 76–81; ¥: Age 71–75 vs 65–70; ‡: Age 76–81 vs Age 71–

4.3. Study III

Tests of muscle function and health related quality of life in healthy older adults in Sweden

The below list summarizes the findings in Study III that investigated the relationship of simple tests of physical functional performance with health-related quality of life in older adults and present reference values in a group of 192 community dwelling persons aged 65-81 yrs.

- There were no significant differences between men and women concerning the physical (PCS) or mental component summary (MCS) of the SF-36.
- There were significant ($p < 0.01$) differences between men and women in the majority of the physical outcome measures except for HRT and 30mWT-self.
- No significant difference between men and women were observed for the two components of SF-36, PCS and MCS.
- 30mWT-self showed the strongest correlation with the PCS both women and men, $r = 0.58$ ($p<0.01$) and $r =0.61$ ($p<0.01$), respectively.
- 30mWT-max showed correlation with the PCS for both women and men, $r = 0.47$ ($p<0.01$) and $r =0.54$ ($p<0.01$), respectively.
- When pooling data between gender a correlation between 30mWT-self and 30mWT-max and PCS was observed 0.57 ($p<0.01$) and 0.51 ($p<0.01$) respectively.
- 30mWT-max correlated with MCS to a small degree, 0.16 ($p<0.05$).
- Pooled data for women and men leg extension muscle strength -right (MVC) showed correlation with PCS by 0.36 ($p<0.01$) and with MCS 0.24 ($p<0.01$).
- Pooled data for women and men hand grip strength - right (MVC) showed correlation with the PCS by 0.34 ($p<0.01$) and 0.20 ($p<0.01$).

In conclusion, this study showed that physical component summary (PCS) of SF-36 health related quality of life correlated to simple clinical physical functional performance tests. Of the physical functional performance tests leg extension MVC and horizontal walking speed at self-selected speed (30mWT-self) correlated the strongest with PCS.

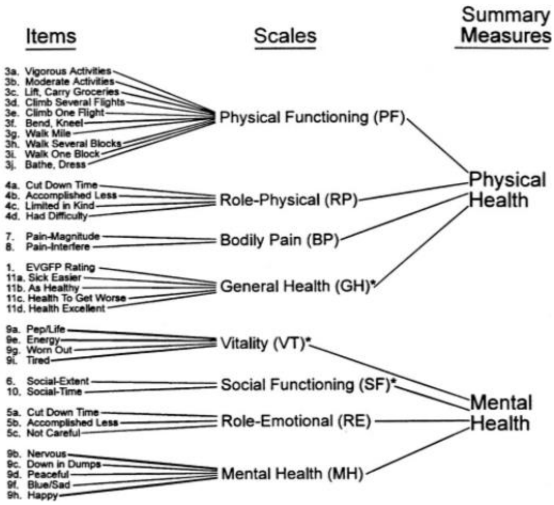

Figure 16. Model of SF-36 measurement (*significant correlation with other summery measures). With permission from Ware et al. (2000) [218].

4.4. Study IV

Effects of age on muscle power, postural control and functional capacity after short-term immobilization and retraining

The below bullet list presents the results of Study IV that investigated the effect of 14 days lower limb immobilization and subsequent retraining on muscle power, postural control and physical functional performance in healthy young and old men. The subject were 20 young (24.4±1.6 yrs) and old men (67.3±4.4 yrs) out of which 11 were young.

Baseline comparisons

- Old men (OM) had lower leg extension power (LEP) (OM: 2.68±0.60 W/kg; YM 4.37±0.76 W/kg).
- OM had greater CoP sway length compared to young men (YM) in both double-leg stance (OM: 204.7±37.7 cm; YM 153.0±70.1 cm, $p<0.05$) and single-leg stance (OM: 1026.8±194.6 cm; YM 566.7±98.6 cm, $p=0.06$).

- During single-leg stance, CoP sway area was greater in OM than in YM (OM: 3676±805 mm^2; YM 1424±279 mm^2; $p<0.05$).
- In the physical functional performance tests OM performed worse compared to YM; Five-Times Sit-to Stand Test (OM: 7.6±1.7 s; YM 5.8±0.6 s; $p<0.05$); 30-sec Sit-To-Stand Test (OM: 20.6±7.3; YM 26.0±3.1; $p<0.05$); 2-min step performance (2MST) (OM: 213±25; YM 289±60; $p<0.05$).
- No difference between YM and OM in horizontal gait speed was noted at baseline.

Effects of immobilization; **Following two weeks of immobilization.**

- LEP decreased by 15% in OM (2.68 ± 0.60 to 2.29 ± 0.63 W/kg) and 17% in YM (4.37 ± 0.76 to 3.63 ± 0.69 W/kg) ($p<0.05$) following immobilization, with no significant difference between OM and YM (p=0.86).
- CoP sway area increased by 45% in OM during double-leg stance after immobilization (217 ± 82 to 317 ± 145 mm^2; $p<0.05$) while staying unchanged in YM.
- Similar trends were noted with an increase in single-limb sway CoP area (3676 ± 805 to 4570 ± 1565 mm^2 [+24%]; p=0.09) and single-leg sway length (1026.8 ± 194.7 vs. 1187.3 ± 247.8 cm [+16%]; p=0.07).
- In YM postural control remained unaffected leading to a between-group difference in single-leg sway length (p=0.036).
- Trends towards a decrease in maximal gait speed in both OM and YM were seen after immobilization, p=0.10 and p=0.08 respectively.
- And similar trends were seen towards a decrease in 2MST (p=0.06) in OM.

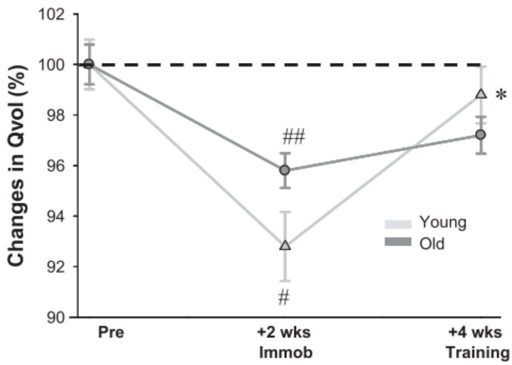

Figure 17. Relative changes in quadriceps muscle volume after 2 wk of immobilization (Immob) and subsequent 4 wk of retraining. With permission from Suetta et al. 2009 *Effects of aging on human skeletal muscle after immobilization and retraining* [101].

Effects of 2 wks immobilization

- LEP decreased by 15% in OM (2.68 ± 0.60 to 2.29 ± 0.63 W/kg) and 17% in YM (4.37 ± 0.76 to 3.63 ± 0.69 W/kg) ($p<0.05$) following immobilization, with no significant difference between OM and YM ($p=0.86$).
- CoP sway area increased by 45% in OM during double-leg stance after immobilization (217 ± 82 to 317 ± 145 mm^2; $p<0.05$) while staying unchanged in YM.
- Likewise, single-limb sway CoP area tended to increase with immobilization (3676 ± 805 to 4570 ± 1565 mm^2 [+24%]; $p=0.09$) along with a tendency for increased single-leg sway length (1026.8 ± 194.7 vs. 1187.3 ± 247.8 cm [+16%]; $p=0.07$).
- In YM postural control remained unaffected leading to a between-group difference in single-leg sway length ($p=0.036$).
- Trends towards a decrease in maximal gait speed in both OM and YM were seen after immobilization ($p=0.10$ and $p=0.08$, respectively).
- And similar trends were seen towards a decrease in 2MST ($p=0.06$) in OM.

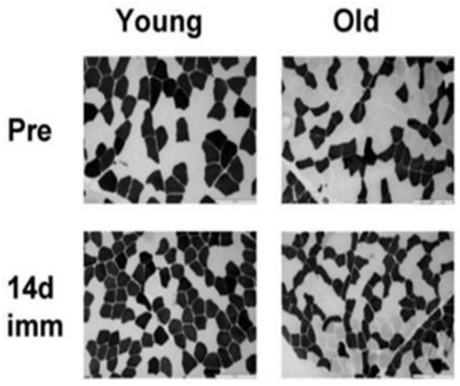

Figure 18. Immobility-induced skeletal muscle atrophy from Suetta et al. 2012 [221] with left image showing percentage decrease in muscle size (mean muscle fiber area) after 4 days of immobilization and after 14 days of immobilization in young (24.4 ±1.6 yrs) and old (67.3 ±4.4yrs). * Time effect, p<0.05 compared to before immobilization, # Age effect, p<0.05 young compared to old within the time point. Group mean data ±SEM. Right image, a muscle histology sample from a biopsy of the resting state of quadriceps femoris before immobilization and after 14 days of immobilization demonstrating Type I (white) and Type II (black) muscle fibers. With permission from Suetta et al.

***Effects of retraining*; Following four weeks of resistance training.**

- LEP of the immobilized leg increased by 17% in YM (3.63 ± 0.69 W/kg vs 4.35 ± 0.79 W/kg) and 16% in OM (2.29 ± 0.63 W/kg vs 2.73 ± 0.56 W/kg), respectively (p<0.05).
- Following retraining OM showed a tendency for decreased CoP sway area in double-leg stance (36%; from 317.0 ± 145.1 to 203.0 ± 76.8 mm^2; p=0.057).
- OM demonstrated an increase in functional performance in 5-STS and 2MST, +20% (p<0.05) and +28% (p<0.05), respectively.

In conclusion, two weeks of lower limb immobilization led to reduced leg extensor power in both young and old, whilst impairments in postural control only were observed in old men. Despite the unilateral immobilization, tendencies were observed for impaired performance during bilateral motor tasks including assessments of maximal gait speed (YM and OM) and 2-min Step Test endurance (OM). Importantly, four weeks of progressive resistance training effectively restored lower limb muscle power and postural control in both young and old men.

4.5. Study V

Comfortable and Maximum Gait Speed in Individuals with Chronic Stroke and Community-Dwelling Controls

The list below presents the findings in Study V investigating the relationship between horizontal self-chosen and maximum gait speed in 104 individuals aged 66.5 yrs (60-80; 4.2) with chronic stroke and whether the relationship differ from that seen in 154 community-dwelling elderly persons aged 72.1 yrs (65-81; 4.7). Further, the study investigated the influence of age, gender, time post-stroke and degree of disability on gait speed. The mean time since the stroke event was 35.2 months (range 6-122).

- Significant differences were noted in both comfortable ($p < 0.001$) and maximum gait speed ($p < 0.001$) between the groups.
- Average maximum gait speed in the stroke group (1.32 m/s) was close to average comfortable gait speed in the control group (1.40 m/s).
- In the stroke group there was a strong correlation between comfortable and maximum gait speed (r_S) = 0.929 ($p < 0.001$).
- In the community dwelling elderly group comfortable gait speed was moderately correlated with maximum gait speed ($r = 0.66$; $p < 0.001$).
- In the community dwelling group younger age was negatively correlated with both comfortable gait speed ($r = -0.36$; $p < 0.001$) and maximum gait speed ($r = -0.39$; $p < 0.001$).
- In the community dwelling group, a significant relationship between higher maximum gait speed and being a man ($p = 0.001$) was shown in the control group, whereas no such relationship was observed for the stroke cohort ($p = 0.179$).
- The unstandardised B coefficient between comfortable and maximum gait speed was found to be 1.41 for the stroke group ($p < 0.001$) and 1.20 for the community-dwelling controls ($p < 0.001$).
- The regression effect size was f^2 stroke= 3.98, and f^2 control= 1.22, and the power=1 in both groups.
- The correlations were shown to differ significantly between groups ($p < 0.001$, Fishers $z = -15.81$).
- For the controls, the unstandardised B coefficient was somewhat reduced (1.07) when the variables age (-0.14, $p = 0.03$) and gender (0.19, $p < 0.001$) were added to the model (Table 4b).

- In the stroke group, no other variable was shown to significantly contribute to the model. In the stroke cohort, age and gender were shown not to be predictive of maximum gait speed in the univariate analysis, whereas the degree of disability according to MRS was shown to be negatively correlated with maximum gait speed ($p < 0.001$), while showing no linkage when included in the multiple analysis.
- Comfortable gait speed among the participants with stroke was the only variable shown to have an independent significant correlation with maximum gait speed.

In conclusion, we observed that self-selected comfortable gait speed in persons with stroke-related disabilities can predict maximum gait speed by multiplying 1.41. This association was significantly different in the control group of 1.20, where comfortable gait speed did not suffice as a proxy for maximal gait speed in the group, suggesting that healthy ageing individuals need to be put to their maximum capacity for detection of decline in physical functional performance.

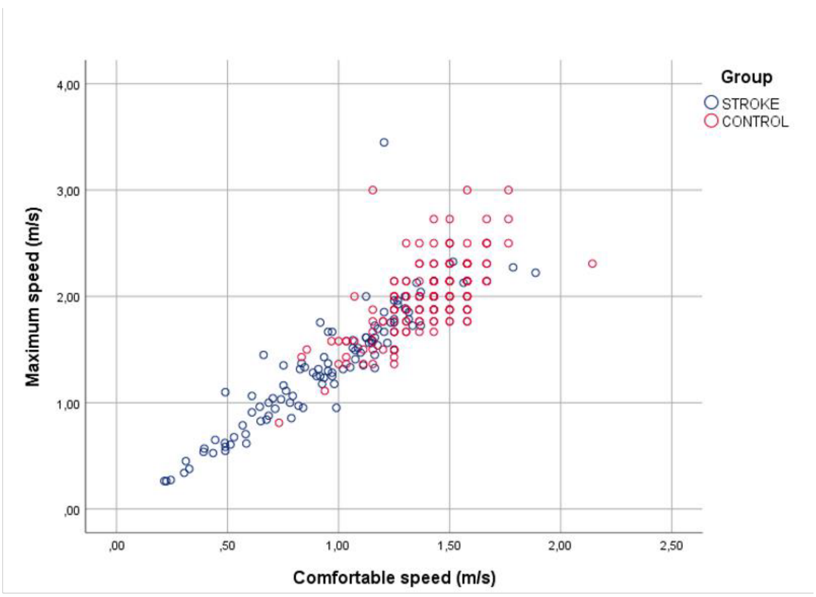

Figure 19. Scatterplot illustrating the association between horizontal comfortable gait speed and maximum horizontal gait speed in individuals with stroke (blue) and community-dwelling older controls (red) (222).

5. Discussion

The novel finding in this thesis was that men demonstrated a steeper rate of decline in Stretch-shortening cycle muscle power (SSC Ppeak) than women with increasing age. This finding emerged as a result of greater age-related losses in men for both force and velocity. Consequently, SSC Ppeak production was observed to converge between genders when approaching old age. The findings in this thesis also indicate that functional capacity appears to deteriorate at an accelerated rate around the 8th decade, whilst at the same time maximal lower limb SSC Ppeak appears to become a stronger contributor to gait speed and postural control. The result also suggests that vertical jump height and maximum horizontal gait speed both can be used as a proxy for lower limb SSC muscle power. This observation is important for clinicians and health professionals who seeks an inexpensive and easily applicable clinical physical performance test evaluate and detect pre-frailty as well as manifest frailty in old adults. As a novel finding, men showed a steeper age-related decline in SSC Ppeak compared to women. Further, in Study IV it was shown that four weeks of active retraining involving high-intensity muscle actions (i.e., heavy-resistance strength training) are effective of reversing the negative effects of short-term (2 wk) immobilization on muscle power, postural control, and functional performance in both young and old adults.

5.1. Study I

Study I is the first (and so far, only one) to examine maximal SSC leg extension power across the full adult life span (18–81 yrs). As the main observation, maximal SSC muscle power (Ppeak) decreased with aging irrespectively of gender, showing a reduction in individuals in their 8th decade corresponding to ~50% compared to subjects in their 2nd decade. Another main and novel finding in this study was that men showed ~50% faster age-related decline rate in SSC muscle power (W/kg/year) compared with women. Maximal SSC leg extension power (Ppeak; W/kg) was greater in men than women throughout the adult life span, however this gender difference diminished when reaching middle-age (35-55 yrs) and older (65-81 yrs), leading to a mering effect between genders in maximal SSC power at old age.

When assessed in men, lower limb SSC Ppeak (W/kg/year) declined at a greater rate per annum compared with women, however, relative rates of decline did not differ between men and women from 20 to 81 years (~8% per decade). Previous reports suggest that lean body mass declines at a steeper rate in women than men per annum [222]. These conflicting results in absolute vs relative rates of decline suggest that in men the age-related changes in the quality of muscle-tendon properties and/ or neuromuscular function is more severe than in women. It has been speculated that qualitative changes as this in adult males could comprise of a greater loss in fast-twitch type II fiber area and/ or greater decrease in tendon stiffness compared to that in women due to a reduction in endogenous testosterone and IGF-1 production [10, 47]. IGF-1 and testosterone levels have been reported to decline in ageing males to such a degree it has been partially considered a deficiency in growth hormone and testosterone [223]. Both growth hormone and testosterone are powerful agents promoting retention and increase in muscle -and bone mass, and muscle protein synthesis. Measured testosterone concentration levels in cross-sectional studies show that men aged 80 yrs have a total testosterone serum concentration of approximately 75% of that at age 20 yrs and the levels of free testosterone concentration of 50% compared to young men [224, 225]. These results coincide well with the present results of similar percentage decline in SSC peak muscle power in men.

In middle-aged and old women, the lower SSC leg muscle power (Ppeak) was explained by a reduction in its velocity component (VPpeak) and not due to a reduction in the force component (FPpeak). Caserotti et al. 2001 reported similar findings where the velocity component appears to be the limiting factor in SSC leg muscle power production and jump performance in ageing women [106, 120]. Women exhibited a marked reduction in VPpeak in the later part of the concentric take-off phase in the CMJ test movement, which roughly corresponds to a semi-extended position of the lower extremity. This timepoint is close to take-off where primarily smaller muscle groups are involved (i.e., the plantar flexors). It is well known that females in general have less developed muscle mass than males [226-228]. This gender difference is attributed to lower levels of growth hormones, and particularly testosterone in women [229]. Women are also affected by reduced levels of estradiol and progresteron at menopause, further contributing to loss of skeletal muscle mass [230]. Behan et al. (2018) noted that women had smaller knee extensor volume (25%) and knee flexor volume (30%) than men with a disproportionately smaller knee flexor (7%) [228]. Peak torque for plantar flexors and dorsi flexors seems to decline in women with increase in movement velocity, while peak power was found to increase with increase in velocity up to 120°/sec according to Suzuki et al. (2001) [231]. However, the combination of a velocity dependent decline in Ppeak, low body weight and decline in estrogen secretion can be additional factors responsible for the high prevalence of falls in women compared to men [209, 232], eventually exposing women to greater risk of loss in functional performance.

In Study I men demonstrated a stronger age-related association than women (R^2 ~46% vs 22%) on the force component of maximal SSC power (FPpeak), which declined at a faster absolute rate in men than in women. Alterations in vivo whole muscle properties, such as a more marked loss in muscle mass and greater negative changes in muscle architecture and/or neuromuscular activation, may be related to the greater rate of reduction in FPpeak in aging men than in women [10, 11, 78, 222]. In vitro, aging may be linked to a decrease in the maximum unloaded shortening speed of single isolated myofibers [233], this could be accompanied by a decrease in single fiber specific force (force/CSA), and both of these factors are likely to have a role in the reported loss in peak power with age [55, 86]. To support these observations, obtained maximum contraction velocity for intact in vivo muscle appears to be reduced in old individuals compared to young [11, 106, 115].

Propulsive force production multiplied by the distance an object is moved is referred to as mechanical work, and during human movement represents the amount of energy generated by the active muscles. In this study men compared to aged-matched women produced greater amounts of work (J/kg) in the concentric CMJ phase ($p<0.001$). As the propulsive force at Ppeak (Fpeak-Con) did not differ between genders in middle-aged and old participants it appears to be due to greater magnitude of vertical body center of mass (BCM). Hence, in the younger group it seems that men generate greater force in the concentric phase whereas in the middle-aged to old groups as men are taller, they generated greater force by moving body center of mass a greater distance. In the downward eccentric CMJ phase higher vertical force production was observed in men across all age groups. Presumably this is a result from higher levels of force exertion the extensor muscles due to greater muscle mass.

RFD has substantial functional implications for older persons since it correlates positively with objective measures of postural control and predicts the ability to maintain postural balance during unexpected tripping, that is, when reversing a fall [8, 87]. This is an important mechanical muscle function parameter as rapid movements involve muscle contractions between 50-200 ms [130]. In both elderly individuals and athletes RFD plays an important role for the ability to perform forceful and rapid movements to control unexpected perturbations in postural control [234]. Impairment in contractile muscle function is represented by the age-related decline in RFD which in turn can have substantial impact on physical functional performance as a reduced RFD decreases the ability to counteract unexpected perturbations, increasing the risk of falls [8, 91].

In Study I rate of force development (RFD) was assessed in the first 100 ms time interval in the eccentric deceleration phase [128, 209]. In the present study it was observed that the oldest group compared to the two younger groups, had a drop in RFD. Notably, women in all three age groups demonstrated greater RFD per kg body mass than men. As maximum force production in the eccentric phase Fpeak-Ecc did not differ between gender in any of the age groups it is suggested that this was the result of jumping strategy, wth women demonstrating a shorter and faster BCM displacement in the eccentric phase, hence requiring high RFD production.

It is likely that due to the complexity of a CMJ, synchronizing a movement over multiple joints and moving the body against gravity, RFD does not reflect maximum capacity for rapid muscle force generation as when evaluated using isolated isometric muscle testing [128, 130]. Instead, it suggests that RFD sampled during a CMJ represents the CNS ability to tune the vertical movement of BCM finely and uniquely, guaranteeing a certain range of movement during the SSC manoeuvre.

A decline in life-time trained individuals maximal muscle strength, power and RFD declined with age have been observed [85, 86]. Nevertheless, the capacity for fast muscle force production (RFD) demonstrated in older strength-trained persons was observed to be four times greater than that reported in sedentary age matched persons [86, 235]. Furthermore, 80-year-old strength-trained lifters exhibited similar maximal muscular power to 60-year-old untrained elderly adults, implying that chronic resistance training can successfully compensate for around 20 years of sarcopenic muscle power reduction within this age range [85]. Caserotti et al. (2008) found a significant deficit (43%) in rapid force capacity (RFD) in 80- and 60-year-old untrained women, which was eliminated after 12 weeks of explosive-type heavy-resistance training, implying that a marked juvenilization in terms of mechanical muscle function (20 years) can be achieved when old people engage in resistance training [190].

In Study I, represented in the in the oldest group were ageing individuals that were all living at home in an autonomy to their best ability. This group had a significant decline in RFD which could be due to an age-related loss in type II fiber area and/or maximal motor unit (MU) firing frequency [10, 11, 236, 237].

A methodological consideration is the instructions given to the subjects which may affect CMJ performance [238]. Talpey, Young, and Beseler (2016) compared two instructions ('just concentrate on jumping for maximum height' [jump height instruction] vs. 'just concentrate on extending the legs as quickly as possible to maximise explosive force' [fast leg extension instruction]), and found that the jump height instruction provided higher values of jump height, peak velocity, and downward displacement, while the fast leg extension instruction provided higher values of peak force [239]. In this study the subjects were instructed to jump as "high as possible and to their maximal ability".

The depth of the countermovement is another important methodological component to consider when testing CMJ performance. Although it is typical to allow participants to choose their desired countermovement depth (i.e., self-preferred CMJ), some research has shown that the countermovement depth can alter numerous CMJ performance factors [240-242]. Possibly, this aspect is reflected in this study by the observed greater RFD per kg body mass in women across all age groups compared to men, se above.

The magnitude of vertical displacement of the BCM during the SSC manoeuvre reduced with advancing age at a similar rate in women and men, which is a new observation. Interestingly, the magnitude of downward BCM displacement (dS-Ecc) had a higher relative drop rate than the size of upward BCM displacement (dS-Con), indicating that the eccentric phase of the SSC movement may be more influenced by aging than the concentric phase. This finding may indicate a lower range of flexor range of motion (ROM) in the hip, knee, and/or ankle joints during the eccentric CMJ phase, as a result of aging-related declines in eccentric strength capacity of the knee and hip extensors [243]. In the takeoff phase (T-Con) of the CMJ we expected a prolonged duration. However, it remained unaffected by ageing in this study as all three age groups spent approximately the same amount of time in the T-Con. On the other hand, the older subjects moved their BCM a shorter distance than that of younger subjects, indicating that older subjects moved their BCM at a slower speed.

In an early study, young women showed stronger pre-activation (potentiation) impact of the eccentric pre-stretch than young men at low pre-stretch loads, whilst men showed greater potentiation effects at high pre-stretch loads [244]. In Study I there was a tendency for older women to better be able to transfer force generated in the eccentric phase into the concentric phase, whilst men's maximal vertical force exertion (per kg body mass) declined faster than women's during the concentric (i.e., upward) movement phase (Fpeak-Con), but not during the eccentric (downward) CMJ phase, as they grew older (Fpeak-Ecc). The greater relative decrease in maximal concentric SSC force production (Fpeak-Con) observed in the male adults tested in the current study suggests that this gender switch of low versus high eccentric pre-stretch loads is largely attenuated by aging. In conclusion, Study I demonstrate for the first time that maximal SSC leg extension power (normalized to body mass) is greater in men than in women throughout adulthood, but that it declines at a faster rate in men, resulting in a progressive convergence in maximal SSC power production between men and women as they get older.

5.2. Study II

The results of Study II show that there is a critical age, ~75 years old, when peak muscle power begins to contribute to greater extent in ordinary ambulatory tasks, implying that older adults are reaching their maximum functional capacity in a variety of activities, regardless of gender. Furthermore, compared to isolated muscle strength, increasing age appears to contribute to a greater extent to the reduction of SSC Ppeak (W/kg), postural balance (sec), and both maximal and self-selected gait speed (m/s) (N). The current data also suggest that maximal vertical JH has a very strong correlation with SSC Ppeak, regardless of gender or age, and that the degree of this association appears to be gradually increasing during the 8th decade.

This is consistent with prior research, which found that as people get older, their contractile force generation and contraction speeds decrease, resulting in a general slowing of specific movement tasks [55, 141, 142]. D'Antona et al. (2003) observed that the concentration of myosin is a major determinant of lower specific force in single muscle fibres in ageing, especially following immobilization. Ageing was also associated with lower velocity of single fibres as changes in myosin properties were observed [55]. In the extensive review of Aagaard et al. (2010) they summarize that the age-related loss in neuromuscular function, which includes changes in maximal MN firing frequency, agonist muscle activation, antagonist muscle coactivation, force steadiness, and spinal inhibitory circuitry, is accompanied and partly caused by an age-related loss in neuromuscular function [10]. The loss of spinal MNs is accompanied by a decrease in muscle fiber quantity and size (sarcopenia), leading to impaired mechanical muscle performance, which leads to a decline in functional capacity during daily tasks [10].

In Study II a linear decline in SSC muscular power and muscle strength in absolute values was seen with increasing age, particularly in males. The oldest-old subjects performed significantly worse than the middle-old subjects, though not significantly so, while the youngest-old subjects did not outperform the middle-old to the same level. These findings support the idea that the oldest-old age group (those above 75 years old) represents a distinct stage of life [245, 246]. In comparison to the decline observed between middle-aged and young males, SSC Ppeak declined up to 100 % faster between oldest-old and middle-aged males (14.7 % vs. 5.9 %). In women a similar trend was noted, where the corresponding declines amounted to 16% and 5%, respectively. In the current study SSC Ppeak did not decline at a constant rate, but rather showed an accelerated decline rate as people approached their eighth decade, as was recently observed in a large-scale population (n=1,305) utilizing concentric-only muscular power testing [21].

Gait speed is a common outcome measure used in the clinic to assess changes in health and physical performance [15, 21, 92, 140, 144, 212, 247]. Gait speed depends on the function and the coaction of the musculoskeletal, visual, central nervous, and peripheral nervous system, as well as cardiorespiratory fitness and energy production and delivery [140]. The complexity of walking has listed walking speed as the "sixth functional vital sign" of older adults [248]. In the present study both men and women in the oldest-old group had lower maximum and self-selected gait speed (30mWT-self/max) than the younger age groups. In particular, SSC Ppeak was a strong contributor to gait speed, notably 30mWT-max (R^2=0.54) in the oldest-old group. The association between peak muscular power of the lower limb and maximum gait speed (current study), skeletal muscle mass, and health support the idea that decreasing gait speed is a functional indicator of aging [21, 140, 144, 248, 249]. Although there is ample evidence of gait speed and the association with age Siglinsky et al. (2015) somewhat surprising reported that gait speed and age had a moderate correlation (R^2=0.04 vs. 0.13/0.15) [250].

Studentski et al. (2011) used data from 9 cohort studies, with data from 34 485 community-dwelling older adults with a mean age of 73.5 yrs with a mean gait speed of 0.92 m/s where gait speed was associated with survival in all studies (hazard ratio per 0.1 m/s, 0.88; 95% CI, 0.87–0.90; P<. 001), and survival increased across the gait speed spectrum, with significant increases every 0.1 m/s [135].

This suggests the importance of same type of measure and settings in order to detect change over time.

In Study II mechanical muscle function (SSC Ppeak, JH, MVC, Grip) appeared to differ between genders across the lifespan, although no gender variations were found for several functional performance-based measures (postural balance, TUG, 30mW). These observations are in line with previous reports, demonstrating significant gender differences for specific muscle function tests [20, 21]. Males have greater absolute and relative lean muscle mass than females at any given age, which helps to explain at least some of the constant gender disparities in mechanical muscle function [21, 250, 251].

Both women and men's relative muscle power has been found to drop after the age of 40 years. The loss in relative muscle power during the first decades of decline was largely attributable to a rise in body mass, but overall was related to a drop in specific muscle power, with no obvious changes in relative leg lean mass [252]. Alcazar et al. (2020) showed that women's body mass and relative leg lean mass decreased steadily after the age of 75 accompanied by an attenuated loss in specific muscle power. This resulted in a slower rate of relative muscular power reduction in women aged 75 years and over. Men, on the other hand, experienced a fall in relative leg lean mass beyond 65 years, which, along with decreasing specific muscle power, resulted in an increased loss in absolute muscle power [252]. These findings, combined with the fact that functional capacity declines more quickly after the age of 75 years, highlight the difficulties in selecting outcome measures with high clinical relevance and sensitivity across a broader age and gender spectrum of older adults to detect a decline in physical activity and thus functional capacity [253]. The variation and pattern of age-related change over time in relative muscle power and its components differ between women and men, as well as between different age intervals [252]. This information is of great importance for the development of effective intervention paradigms and their adaptation to gender and age of varied target populations. The inherent loss of skeletal muscle mass and maximal muscular force is one of the characteristics of human aging. Reports on a decline in lean muscle mass across lifetime is approximately 23% and 19% in men and women respectively [21]. Although not as severe as previously thought, age-related skeletal muscle mass loss can reach up to 50% by the 8–9th decade of life [21, 254]. The significant decrease in physical functional performance seen in the current group of oldest-old people is most likely due to a faster loss of muscle mass and resulting deficits in mechanical muscle function (force, power) as people get older.

Age-related decline in muscle size and function can be influenced by physical activity levels as well as intrinsic factors [21]. Physical activity and resistance training are significant strategies to develop muscle mass, strength, and power, and are considered one of the most important components in frailty prevention [255, 256]. Muscle power is a more reliable predictor of frailty than muscle strength because it is the product of contractile force and movement velocity [16, 90]. As a result, physical exercise aimed at minimizing physical dependency in the ageing should be structured to maximize muscular power as a countermeasure [73, 107, 257].

Although the force plate method is regarded the gold standard method for quantifying SSC lower limb muscle power, it is both expensive and time consuming, making it best suited for research purposes. On the other hand, it remains critical to detect pre-frail persons who are on the verge of being unable to manage daily activities, hence other outcome measures related to peak muscle power must be identified.

The current data show that maximal vertical JH has a very strong correlation with SSC Ppeak, regardless of gender or age, and that the increase of this association appears to be gradually increasing during the 8th decade. JH has been shown to be superior to standard outcome measures in discriminating between sarcopenic and non-sarcopenic elderly persons, possibly due to this particular association, but also due to its substantial correlation with lean mass (DXA) and numerous physical functional performance tests [250].

In Study II maximal vertical JH had a very strong correlation with SSC Ppeak, regardless of gender or age, and this association appears to get gradually stronger during the 8th. decade.

The current plantar flexor fatigue test (HRT), on the other hand, was difficult for the ageing subjects to execute in a standardized manor. The test is challenging because it requires not only plantar flexor muscle strength, but also postural stability and the ability to keep up with the cadence of the test movement. In retrospect, this fatigue protocol may have been too demanding for some participants, resulting in test failure due to a lack of postural stability and pace control rather than muscular fatigue. In contrast, standing on one leg with eyes open to assess postural control may not have been sufficiently taxing for the two younger age groups, where the majority of the individuals reached a ceiling effect (test terminated when exceeding 30 seconds of single leg standing). When the subjects were reaching their 8th decade, the age-related reduction in physical functional performance appears to accelerate, whereas maximal lower limb SSC muscle power appears to play a larger role in balance and gait capability.

In this study JH has been shown to be superior than traditional outcome measures in discriminating between sarcopenic and non-sarcopenic elderly persons, possibly due to this particular association, but also due to its substantial correlation with lean mass (DXA) and numerous physical performance tests [250, 258]. In a recent study the STS muscle power test proved to be a more clinically relevant tool compared to traditional STS time values [13]. Perchance, combining the assessment of JH as a proxy measure of lower limb muscle power with the recording of 30mWT-max and STS power test in old adults could provide a more accurate predictor of pre-frailty. Taking into account the minimal space, low cost to execute and few material requirements this should make an excellent choice in a clinical setting.

Physical activity and pre-habilitative training would be expected to delay or mitigate the negative effects of age on maximal muscle strength and muscle power, resulting in enhanced quality of life in the ageing population [259]. A deeper understanding of the impact of age and gender influence on these commonly used outcome measures is essential for developing test paradigms that can more accurately identify pre-frail people at risk of losing their independence. In conclusion, when people enter their 8th decade, the age-related reduction in functional capacity appears to accelerate, whereas maximal lower limb SSC muscle power appears to play a larger role in balance and gait capacity. This study suggests that when people get older (+75 years), incorporating exercise programs to promote maximal muscle power becomes more significant. The current findings also highlight the need for effective clinical diagnostic tools to assess skeletal muscle power decrements, muscle strength impairments, and functional capacity reductions in the clinical setting in order to facilitate early intervention activities aimed at preventing functional capacity loss and allowing individuals to maintain or even improve late quality of life.

5.3. Study III

In Study III the relationship between health-related quality of life (HRQL) evaluated with the SF-36 questionnaire and physical functional performance tests was investigated in a random sample of 192 persons aged 65-81 years. The main result show that PCS correlated the strongest horizontal gait speed 30mWT-self r = 0.57, closely followed by 30mWT-max r = 0.51. Mental component summary (MCS) correlated only with the parameters including force only, leg extension (MVC) and hand Grip strength (MVC) by r = 0.24 and r = 0.20, respectively. In line with previous research no significant difference between gender in the two summary scores PCS and MCS was observed [260].

Loss of function is an independent predictor of negative consequences in community-dwelling older people, and it is associated with a lower quality of life in the ageing population [261]. Quality of life is related to health and the ability to live a healthy lifestyle, overcome morbid illness, and is dependent on the personal satisfaction of each individual [262]. It also take into account an individual's physical health, psychological state, level of independence, social relationships, and relevant environmental characteristics [263].

The results in this study are in line with previous results where the PCS of the SF-36 and chair rise time (r =0.58;) and stair climb time (r =0.48) had the highest univariate relationships between function and psychosocial factors. In addition, self-reported measures of general health and physical functioning by SF-36 were found to be predictive of functional performance. Further, they conclude that plantar flexor peak muscle power and dorsi flexor muscle power of the ankle are important predictors of chair rise performance and stair climbing, concluding that muscle power from the ankle is an essential component of physical functional performance in 75 year old women [231]. As previously mentioned, the plantar flexor muscle is critical in gait since the recruitment of the muscle groups is necessary for both postural control and propulsion [41, 43].

Due to the population's progressive aging and the related increase in older adults with mobility limitation, a significant goal should aim at selecting outcome measures that are easily applicable, inexpensive, are quick to execute, reliable and valid. All the outcome measures have shown to be valid and reliable in a wide range of healthy and disease specific cohorts [203, 208, 212, 217, 264-266]. Surprisingly, we observed the strongest relationship with PCS and 30mWT-self, both in pooled data (n=192) and split by gender. Split by gender in absolute values (m/s) no difference between groups were observed. Both leg extension muscle strength and heel-rise test correlated to 30mWT-max. In regard to gender difference for these measures, not too surprisingly, men walked faster than women 1.96 m/s vs. 1.87 m/s, produced greater maximal voluntary contraction (N) than women, but did not outperform them in the HRT.

The outcome measure that showed a strong relationship to the dual components in the SF-36 is recognized as valid proxy for SF-36. However, the association between physical performance tests and the mental components (MCS) of the SF-36 was minimal. On the other hand, the pattern of correlations observed for PCS speaks in favor of the 30mWT.

HRQL may be influenced by the sorts of physical exercise that older persons engage in. We believe they will report a higher quality of life if they are participating in something they enjoy. The significant correlation between the PCS and the 30mWT could be due to a sense of familiarity with the action. When compared to the other performance-based tests, the walking speed test is most likely the most familiar to the individuals. As a result of their increased comfort and confidence, they may have performed better. Hence, prior to the actual test day, a familiarization day for the outcome measures would, in hindsight have been appropriate.

In Study III data it is demonstrated that there is correlation between HRQL and 30mWT-self. Several studies have suggested that walking speed alone is the most sensitive physical performance measure for predicting the onset of health related events [267-270]. A slower gait speed over a distance of 4 m was found to be predictive of death (threshold of 1 m/s) and medical problems (hospitalization, disability, falls, cognitive decline) in ambulatory older individuals, with a threshold of 0.8 m/s [271]. This is further supported by the relationship between leg extension power and maximal walking speed [14]. The lower end of the range might be thought of as the bare minimum, below which it is nearly difficult to complete the task. The top of the range might be thought of as the "safe" level, at which an increase in power does not enhance the likelihood of achieving that walking pace, but rather acts as a safety margin. The majority of those with a maximal walking speed in the range of 1.00-1.29 $m \cdot s^{-1}$, for example, had leg extension power below 9.5 Wkg^{-1}, which would appear to be the upper limit of the critical range of leg extension power for that walking speed. Only 12% of individuals who walked faster than 2.00 $m \cdot s^{-1}$ had maximal leg extension power below that threshold. As a result, for a walking speed greater than 2.00 $m \cdot s^{-1}$, 9.5 Wkg^{-1} might be considered the lower or minimum level of the crucial power range [270].

In unpublished data from clinical trials, physical activity (PA) had a positive impact on perceived physical function in older women. Changes in muscle strength and balance were strongly connected with changes in psychological and physical function. More importantly, improvements in self-efficacy has shown to have a significant effect on changes in self-reported function ($p > 0.01$), and the effect on performance-based function approached significance ($p = 0.08$) [272]. The mechanism for a change in quality of life as a result of physical activity may be determined by the outcome that is most important to older people. Physical activity is clearly linked to health outcomes such as quality of life [272, 273]. One must consider the contrast between subjective evaluations of functional abilities and satisfaction with these abilities. There are numerous examples of persons with having impaired function yet are content with their restrictions and life in general. In Martin et al. (1999) older persons with knee osteoarthritis who had functional limitations but put a lower importance on physical function were happier with their functional status than their counterparts who had functional limitations but continued to value physical function highly. However, those who appeared to have adapted to their illness by placing a low value on function also reported being less active [274]. Hence, the findings conclude that inactivity in ageing is a risk factor for subsequent disability [275]. Frailty is an increasing public health priority that is linked to disability, poor quality of life, and increased mortality in the elderly, and is strongly influenced by muscle function impairments [276]. As previous studies suggest, the inclusion of horizontal gait speed and SF-36 PCS can provide as a useful tool together with JH to identify early stages of frailty and increase health related quality of life by implementation of countermeasure physical activity interventions [65].

5.4. Study IV

In Study IV the main finding was that two weeks of unilateral lower limb immobilization reduced maximal leg extensor power in both young (-17%) and older (-15%) men, as well as increased the double-leg stance postural CoP sway area in older men. Furthermore, when young and old people were compared, the sway length of the immobilized leg increased more in the latter. The unilateral immobilization period had no effect on physical performance, with the exception of trends toward decreased maximal gait speed (in both young and old men) and a decrease in 2mST endurance capacity in older men. However, four weeks of supervised resistance-based retraining improved leg extension power and postural control in both young and old men, as well as STS performance and maximal gait speed in the older men.

Following trauma, surgery, or serious infectious diseases, prolonged bedrest is a common experience, particularly in the ageing population. The lack of gravitational stimuli due to bed rest can lead to loss of balance and other functional impairments with serious implications for the single individual [277, 278]. The decreases in muscle contractile function caused by disuse appear to occur more rapidly in the first few days, followed by an attenuated decline rate as the disuse period progress [173, 279-281].

In quite stance tasks the lower leg and foot muscles are primarily involved to control body oscillation above the support surface [282, 283]. In a study by Fitts et al. (2001) they observed that PLF were more susceptible to bed rest than dorsal flexors [284]. It is generally known that skeletal muscle atrophy occurs in response to both real and simulated microgravity exposure and animal studies demonstrate that postural muscles, which have a higher percentage of slow fibres than non-postural muscles, are more prone to atrophy [285-287]. Compiled data on relative loss of PLF over time compared to knee extensors CSA or volume show that both muscle groups atrophied in a non-linear fashion, and atrophy in PLF were greater than that of knee extensors [171]. In a review by Narici et al. (2011) they observe that the decline in muscle volume tend to be smaller than that of CSA and suggest that the difference in atrophy between the muscle groups may reflect the different loading patterns and are likely influenced by the protein turnover. Due to the size of the PLF (50 % smaller) in relation to knee extensors, they are likely to be subjected to a correspondingly higher loading during locomotion as body mass is shifted forward, hence unloading effects PLF to a greater extent [171].
However, the contractile function of the knee extensor muscles is important for maintaining functional independence [9, 288]. Maximal knee extension muscle strength decrease due to disuse is disproportionately larger than the observed muscle mass or volume indicating a loss of muscle quality [101, 173, 174, 281]. Studies of older adults have found that their knee extensor muscle contractile function is negatively affected to a similar or slightly greater degree than that of young people [101, 174, 280].

Data from Hvid et al. (2011), demonstrate that the decrease in knee extensor muscle quality after 14 days of whole-leg immobilization in YM and OM partly could be ascribed to decrements in vastus lateralis single muscle fiber specific force as well as altered force – Ca^2 + relationship properties, emphasizing that changes in single muscle fibre have consequences at the whole muscle level [289, 290]. In previous studies maximal isometric knee extensor strength decreased by 9.7% and 16.4% in

YM and OM after only 4 days of lower limb immobilization, equivalent to a daily decline rate of 2.4 and 4.1 % respectively [291]. Suetta et al. (2009) observed that after immobilization; YM had greater muscle atrophy and greater changes in vastus lateralis muscle pentation angle compared to OM; OM had a reduction in muscle activation was observed following immobilization; OM had a diminished capacity to restore muscle architecture and size with re-training, and further suggest that the adaptive plasticity for YM and OM differed in regard to skeletal muscle mass and CNS function after unloading and re-training [101].

In Study IV the YM and OM were both healthy, recreationally active men with normal anthropometric features (weight, height, and BMI) and physical function (LEP, GS, and STS), respectively, and there was no difference in habitual physical activity levels between the groups. In comparison to YM, OM showed a 25% deficit in LEP at baseline, which was exacerbated when normalized to bodyweight (a 39 % deficit), which was consistent with previous findings in larger cohorts of men and women throughout the age spectrum [21, 252, 292]. As expected at baseline, habitual gait speed did not differ between young and old and age-related differences were primarily observed in outcome measures requiring high muscle power and/ or postural motor control (LEP, 30s-STS, CoP sway area/length). Age-related changes in postural control were particularly noticeable during single-leg evaluations, which was consistent with earlier findings [293]. Specifically, older men had a larger single-leg stance sway area (+158%) and sway length (+81%) than younger men, although the differences were less obvious during double-leg stance sway testing, where older men had a higher CoP excursion (+34%) than younger men.

The effects of immobilization were particularly significantly increased in CoP sway area and observed during double-leg stance in OM (+46%) after 2 weeks of immobilization, as well as tendencies ($p=0.07–0.09$) toward increases in single leg sway length (+16) and sway area (+24%), see above. The deleterious effect of lower limb immobilization on neuromuscular function may explain a major part of the unfavorable impact of immobilization on postural control [291]. In fact, we and others have previously shown that short-term immobilization has a greater impact on neuromuscular function in old adults compared to the young, as measured by quadriceps femoris activation and rapid force capacity and mechanical muscle performance during fast contractions of the knee extensors [280, 289]. Koryak et al. (2002) showed in a small cohort, changes in the contraction properties of the triceps surae muscle after 7 days of unloading with: drop in MVC (18.9 %, $p<0.01$), decrease in RFD and voluntary peak force, a decrease in force steadiness in MVC (44.1 % $p<0,001$), a muscle mass decrease and changes in the muscle and tendons elastic components [294]. However, in the present study muscle power decreased to a similar degree in both YM and OM, as observed with Rejc et al. (2018) when comparing changes in maximal lower limb muscle power in young (18–30 years) and older (55–65 years) adults following 2 weeks of bed rest, muscular power decreased to a similar level in both young and senior people in the current study [295]. It's possible that the lack of age-related changes in muscle power is due to a lower sensitivity of assessing maximal leg extension muscle power compared to rapid force capacity testing (rate of force development: RFD) or too small a sample size. On the other hand, lower limb immobilization showed a negative impact on postural control in OM only, which could be explained in part by an age-related reduction in maximal lower limb muscular power at baseline, which was then further reduced after two weeks of immobilization. Notably, physical functional performance was not greatly affected by the period of immobilization although trends ($p=0.06$–0.09) towards a decrease in maximal GS (YM, OM) and Step Test endurance (OM) were noted. These findings suggest that the bilateral functional performance tests (GS, STS, Step Test) are less sensitive to the unilateral lower limb immobilization regimen than single-limb leg extensor muscle strength and postural control testing.

Resistance training was specifically chosen in this study to facilitate in the restoration of muscle function as it is a well-known method for increasing muscle mass and neuromuscular performance (e.g., causing gains in muscle strength, rate of force development and maximal muscle power, respectively) [10, 296, 297]. Notably, responses to retraining described in the literature, particularly in older adults, vary significantly depending on the type and duration of exercise intervention, as well as the strength/power/functional measures studied [101, 174, 295, 298]. In this study, four weeks of resistance retraining appeared to be effective in restoring pre-intervention muscle power in both YM and OM. In contrast, after 2 weeks of bed rest, Rejc et al. (2018) found that 2 weeks of mixed retraining (six sessions total, including resistance training) was enough to restore muscle power in young but not old men [295]. However, in the study by Rejc et al., the retraining program lasted the same amount of time as the disuse phase (14 days), which may not be long enough to completely reverse muscle power in older persons. Earlier studies from our own group has demonstrated that older adults recover from short-term (2-week) immobilization at a slower rate than young individuals [101, 174]. Specifically, after two weeks of unilateral lower limb immobilization, four weeks of progressive resistance based retraining resulted in 100 percent recovery of muscle mass and rapid force capacity (RFD) in YM but not OM [172, 174]. In the current study, old men showed gains in functional capacity with retraining, as seen by significant improvements in the 5TST and the 2-min ST, which were not seen in young men, likely due to a ceiling effect.

As proprioception is important for balance control and plays an essential part in postural control in humans while standing, continuous calf muscle activity is required [168]. In the present study, the RT included multi-joint leg press exercises documented to promote and stimulate neuro muscular function in both hip, and leg extensors and plantar flexors [299, 300]. Previous study has linked maximal knee extensor strength to the risk of falling in elderly people with osteoarthritis, implying that the knee extensor muscle is important in postural control. De Zwart et al. (2015) noted a connection between maximal knee extensor strength and the risk of falling in elderly persons with osteoarthritis, indicating that the knee extensor muscle is involved in postural control [301].

Importantly, the results of this study show that four weeks of active retraining involving high-intensity muscle actions (i.e., heavy-resistance strength training) appears to be effective in reversing the negative effects of short-term (2 wk) immobilization in both young and old adults in terms of muscle power, postural control, and functional capacity. The findings of this study may contribute to a better knowledge of the mechanism and range of impairments associated with loss in muscle function and postural control after disuse, which could aid in the development of effective countermeasure intervention strategies for old adults. Such interventions could help reduce the risk of functional deterioration and increase quality of life in the ageing population.

5.5. Study V

In Study V the bodily impairment after suffering a stroke result in a slowing of horizontal gait speed in persons 66.5 (60-80) years compared to older controls 72.1 (65-81) years. Both in terms of comfortable and maximal speed. The control group showed mean comfortable and maximum gait speeds that were 0.5 and 0.6 m/s faster than the stroke group, respectively. Controls' average comfortable gait speed was 1.4 m/s, and their average maximal gait speed was 2.0 m/s, compared to 0.92 and 1.32 m/s for the stroke group, respectively. Comfortable gait speed could work as a proxy measure for maximal gait speed in the stroke cohort, but not in the community dwelling group.

An impairment in a body structure or function can lead to mobility impairments and participation restrictions, as well as decreased functional ability and disability, depending on the severity of the impairment [93]. The neuromuscular system has a significant impact on functional capacity as people age and reduced muscle power is the most common neuromuscular consequence linked to functional limitations and disability in the ageing [10, 302]. Rather than selecting control subjects who were free of ailments and pathologies, we chose to include older people who functioned independently but were not necessarily free of pathologies, thus representing a community-dwelling group of individuals who could be representative of the general population. As a result, we feel they reflect elderly people who, despite some disorders, remain fairly active.

The slowing of movement caused by age-related reductions in force production and contraction speed (i.e., reduced muscle power) is a key indicator of old age. Increased stance width, greater time spent in the double support phase, increased bent posture, and decreased propulsive power output in the push-off phase are other gait characteristics that alter with age [10, 55, 141-143]. Some of these traits are also observed in stroke sufferers, a group where falls are common [153]. Within 6 months after a stroke, 25–37% of stroke survivors fall, and 23–50% fall 6 months later [303-306]. In community dwelling older persons over a period of a year 32% fell one time, 24% fell and had serious injuries and 6% had fractures. The rate of falls in older persons living in institutions, this rate was significantly higher [307]. Accidental falls and fall-related injuries, such as hip fractures, can result in severe impairment and have a negative impact on the persons overall health. A decrease in muscle mass, strength and function may be the result due to immobilization after a fracture, major surgery, and hospitalization, with possibly fatal results [308-310].

In Study V the community dwelling older subjects in the control group demonstrate higher horizontal gait speed in both comfortable and maximum pace the younger they were ($p<0.001$) respectively. In the stroke group, average *maximum* gait speed was nearly equivalent to the average *comfortable* gait speed in the control group, 1.32 m/s vs. 1.40 m/s respectively. In the stroke group, correlations between the two different gait speeds were strong (r_S) = 0.929 ($p < 0.001$) suggesting that the group have little, or no reserve capacity performing close to their threshold. This threshold in community dwelling old persons has been suggested to enter around the 8th decade, one to two decades later than in the stroke population [21, 145].

In a classic study by Skelton et al. (2002) women aged 65 and up, with and without a history of falls, showed lower limb muscle power combined with asymmetry, and suggest that asymmetry between limbs may be more predictive for future falls than more traditional measures [90]. Those with stroke and hemiparetic asymmetrical gait also showed lower velocity and cadence and were more prone to fall [153]. Walking is a continual shift between instability and stability, where 80% of the gait patterns is unilateral stance [134]. In horizontal gait BCG both falls forward and shift from side to side outside the base support [133]. In stroke sufferers a significant relationships between mediolateral BCG displacement and area was observed in fallers compared to non-fallers [153]. Damaged motor control and severity of spasticity is reportedly markedly higher in fallers than non-fallers in stroke patients [153].

As the central nervous system requires more resources to maintain postural control after stroke, walking in out-door environment can pose as a challenge, performing other tasks at the same time, referred to as dual tasking. In contrast, skilled movement with automaticity, cognitive attention is rarely needed which in turn facilitate performance. Lack of sufficient gait automatic after stroke and gait disability, dual task gait speed, was related to the level of motor recovery [311]. Putting it to a context of physical function in and around one's environment it can pose as a problem for persons with stroke, older, or disabled persons. International standards for pedestrian crossings are 1.2 m/s, which the stroke group in this cohort just managed by 0.12 m/s in their maximal gait speed but would not meat if they were to walk comfortably (0.92 m/s) [151]. Factors like time since stroke, postural control and fear of falling are all associated to gait speed and walking out-doors [312]. In the present study the unstandardised B association between comfortable and maximal gait speed was found to be 1.41 (p0.001) in the stroke group, in line with 1.40 in Bohannon et al. (1992) study [313]. In the community dwelling control group, the corresponding uncorrected relationship was 1.20. In a previous study the oldest-old (76-81 yrs) had lower maximal and self-selected gait speed compared to the two younger groups 65-70 years and 71-75 years, where no difference were observed [145]. The association between peak muscular power and maximum gait speed, skeletal muscle mass, and health support the idea that decreasing gait speed is a functional indicator of aging [21, 140, 144, 248, 249].

In this study individuals with chronic stroke and hemiparesis had strong correlation between comfortable self-selected horizontal gait speed and maximum gait speed. In the aged, matched control group of community dwelling individuals there was a moderate correlation between self-selected gait speed and maximum gait speed. In this study we concluded that maximum gait speed in persons with stroke-related disabilities can predict maximum gait speed when multiplying 1.41 with comfortable gait speed. This association was significantly different in the control group of 1.20, where comfortable gait speed did not suffice as a proxy for maximal gait speed in the group, suggesting that healthy ageing individuals need to be put to their maximum capacity for detection of decline in physical functional performance.

6. Adverse events and missing data

In Study I and II 37 old persons were excluded due to arthorplastic surgery in the lower extremities or due to low DEXA values and hence not judge fit to jump. One person was excluded due to language, not speaking Swedish. One person in the age group 65-80 years turned 81 years during inclusion period. In Study IV one OM was excluded at baseline for reasons not related to the study.

7. Ethical considerations

Ethics approval was granted by the Regional Ethical Review Board in Gothenburg, Sweden (Dnr: 140-07, 152-10, 549-12) and The Ethics Committee (Copenhagen and Frederiksberg, Denmark) approved the conditions of the study (KF01–322606). The studies were conducted in accordance with relevant ethical guidelines. Written informed consent was obtained from each participant before inclusion in the studies and all participants were told they could withdraw from the study at any time. All included studies comply with the Declaration of Helsinki.

8. Limitations

8.1. Study I

In Study I there was a cross-sectional design may be confounded by interindividual age-related changes in physical activity levels and other living habits, which is a potential methodological restriction. On the other hand, performing long-term longitudinal research only at the intraindividual level by study participants, demonstrating a steady fall in physical activity levels with age, will pose comparable issues. The lack of familiarization can also pose as an issue as the novelty of the test prevented the subjects to perform at their maximal capacity. On the other hand, all the subjects were allowed practice jumps in a sub-maximal manor. As a strength, the same person was the test leader throughout the study, minimizing the risk for adverse protocol events.

8.2. Study II & III

The study protocol included a range of well-established physical performance tests for function and maximal muscle strength that are commonly used in the clinical setting. The chosen plantar flexor fatigue test (HRT) was highly challenging for this group to perform, especially for the oldest-old. The test is demanding as it requires simultaneous plantar flexor muscle strength, postural control, and a certain ability to follow the test pace set by a metronome. In hindsight, it was too demanding for several of the participant as test failure was due to lack of pace control, lack of postural control, to little movement (not reaching target height), instead of muscle fatigue. On the other hand, this is a result in itself. In contrast, standing on one leg with eyes open to assess postural balance may not have been sufficiently challenging for the two younger age groups, where the majority of the subjects reached a ceiling effect (test terminated when exceeding 30 seconds of single leg standing). As most falls occur in dynamic situations, static test may not be challenging enough [315]. The ambition for these studies was to include persons from different areas with in the municipal. However, due to limitations in the language skill, only persons versed in Swedish were eligible for testing. In study III more women than men were eligible.

8.3. Study IV

In Study IV there are a few potential limitations that should be mentioned. To begin with, the participants in this study were all healthy adult men. As a result, extrapolating the findings to other populations, such as people with pathological diseases or frail older adults, should be done with caution. Secondly, as falls and insufficient postural control due to sudden perturbations, often occurs in dynamics situations, it is implicated that the static CoP outcome measure int the present study may not be challenging enough to predict falls [315].

8.4. Study V

In Study V the two groups horizontal gait speed was measured with different distances', 10 m for the stroke cohort and 30 m for the community dwelling and bias cannot be ruled out. However, the stroke group with overall motor impairment and slower speed of movement might not have been able to perform the longer distance to a satisfactory manner. The community dwelling group had overall high level of speed, indicating no endurance difficulties, and are representative for older individuals.

9. Conclusions

- Maximal SSC muscle power (Ppeak) is severely affected by aging irrespectively of gender, with a reduction for individuals in the 8th decade by ~50% compared with subjects in their 2nd decade.

- Men showed ~50% greater age-related decline rate in SSC muscle power (W/kg/year) compared with women, leading to a convergence in maximal SSC power production between women and men.

- When approaching the 8th decade, the age-related decline in functional capacity appears to accelerate, while at the same time maximal lower limb SSC muscle power seems to contribute more strongly to balance and gait capacity, suggesting a threshold and critical age.

- Vertical JH is suggested as a proxy measure for SSC muscle power, even in the oldest old, as it has a very strong correlation with SSC Ppeak, regardless of gender or age. This degree of association appears to be gradually increasing with increasing age.

- The inclusion of horizontal gait speed and SF-36 PCS can provide as a useful tool together with JH to identify early stages of frailty and increase health related quality of life even in the oldest-old.

- Two weeks of unilateral lower limb immobilization reduced maximal leg extensor power in both young (-17%) and older (-15%) men.

- Immobilization affected postural control to a greater extent in old men than young.

- However, four weeks of supervised resistance-based retraining improved leg extension power and postural control in both young and old men and improved STS performance and maximal gait speed in the older men.

- Old men demonstrated adaptive plasticity in both skeletal muscles and the neuromuscular system in response to strength training (resistance exercise).

- Maximum gait speed in community dwelling old persons could not be estimated by multiplying comfortable gait speed with 1.20, suggesting that healthy ageing individuals need to be put to their maximum capacity for detection of decline in physical functional performance.

- However, in persons with stroke-related disabilities comfortable gait speed when multiplying 1.41 with comfortable gait speed could be used as proxy for maximal gait speed.

10. Clinical implications

- Ageing is associated to decrease in muscle mass and/or parallel with impairments in mechanical muscle function, strength and decline in functional capacity.

- Ageing lead to decline in muscle peak power which is essential in order to execute IADL. Instead of muscle power measure in a laboratory with expensive and time-consuming measures, jump height can serve as a proxy outcome measure for muscle power even in the oldest-old.

- Walking test at comfortable self-selected speed appears suitable for estimating physical function and deterioration due to chronic disease. Walking test at a maximal speed be better suited for estimating subjective general health and skeletal muscle mass function.

- For early detection of physical functional decline, it is suggested that healthy ageing individuals need to be put to their maximum capacity for early detection of decline in physical functional performance.

- Men and women seem to rely on different strategies in the development of peak power, where men tend to rely more on the force development and women on the velocity component and young-old and middle-old performed similarly in functional performance test. Both results suggesting more individualized test protocols in clinical situations.

- Healthy elderly can effectively benefit from participating individualized low-frequency training programs aiming at targeting explosive muscle actions.

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