MINNA SAVINAINEN

Physical Capacity and Workload among Ageing Workers

ACADEMIC DISSERTATION
To be presented, with the permission of
the Faculty of Medicine of the University of Tampere,
for public discussion in the small auditorium of Building B,
Medical School of the University of Tampere,
Medisiinarinkatu 3, Tampere, on September 3rd, 2004, at 12 o'clock.

Acta Universitatis Tamperensis 1025

ACADEMIC DISSERTATION
University of Tampere, School of Public Health
Finnish Institute of Occupational Health
Finland

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http://granum.uta.fi

Cover design by
Juha Siro

Printed dissertation
Acta Universitatis Tamperensis 1025
ISBN 951-44-6047-2
ISSN 1455-1616

Electronic dissertation
Acta Electronica Universitatis Tamperensis 370
ISBN 951-44-6048-0
ISSN 1456-954X
http://acta.uta.fi

Tampereen Yliopistopaino Oy – Juvenes Print
Tampere 2004

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List of Original Publications

The study consists of the following original publications, which are referred to in the text by Roman numerals (I–IV). Some previously unpublished results are also presented.

I Savinainen M, Nygård C-H, Korhonen O and Ilmarinen J (2004): Changes in Physical Capacity among Middle-Aged Municipal Employees Over 16 Years. Experimental Aging Research 30: 1–22.

II Savinainen M, Nygård C-H and Arola H (2004): Physical Capacity and Work Ability among Middle-aged Women in Physically Demanding Work – a 10-year Follow-up Study. Advances in Physiotherapy. In press.

III Savinainen M, Nygård C-H and Ilmarinen J: Workload and physical capacity among ageing municipal employees – a 16-year follow-up study. International Journal of Industrial Ergonomics. Accepted.

IV Savinainen M, Nygård C-H and Ilmarinen J (2004): A 16-year follow-up study of physical capacity in relation to perceived workload among ageing employees. Ergonomics. In press.

Abbreviations

AET = Arbeitswissenschaftliche Erhebungsverfahren zur Tätigkeitsanalyse
BMI = body mass index
HR_{max} = maximum heart rate
% HRR = heart rate range
OHWL = objectively high physical workload
OLWL =objectively low physical workload
PHWL = perceived high physical workload
PLWL = perceived low physical workload
RPE = rating of perceived exertion
$RPE_{mean\ work}$ = mean of RPEs during one working day
VO_{2max} = maximum oxygen consumption

Abstract

Health and functional capacity form the basis for human resources and working ability. Previous studies have yielded physical capacity changes of a different level with age. The changes in physical capacity depend on gender, physical activity level, chronic diseases, muscle group and type of muscle work. Moreover, the type of job may be of great importance for either training or wearing effect on the physical capacity involved. The main purpose of this study was to ascertain changes in musculoskeletal and cardiovascular capacity in relation to different workloads during the long follow-up period among ageing workers. The second aim was to find out if physical capacity among employees with different workloads is associated with the assessment method of workload (i.e. subjectively and / or objectively assessed).

The data were obtained by physical capacity measurements in laboratory, workload assessment during work and postal questionnaires. The first study group consisted of 129 middle-aged subjects, who were followed over 16 years. The subjects were on average 51.5 years old and were all employed in the municipal branch (physically and mentally demanding work) at the beginning of follow-up in 1981 and 67.3 years in 1997, when the most of the subjects had retired. The second study group consisted of 60 women who worked in a food factory in physically demanding jobs at the beginning of the 10-year follow-up. Their mean age was 52.3 at the beginning and 62.9 years at the end of follow-up.

In general, an age-related decline in physical capacity was observed. During the follow-up period, the average physical capacity of the workers decreased by approximately 1.0% per year. The study showed that the greatest changes occurred in muscle strength among men and among women in the flexibility of the spine, trunk muscle strength, in limbs endurance and in aerobic capacity. The smallest changes were noted in anthropometrics. The decrease of physical capacity was greater among men than among women, although women had more individual variations.

Among women the differences in physical capacity between different workload groups were more evident than among men. In general, the women with low workload had better physical capacity than the women with high workload at the end of the follow-up periods. Instead, the men with low workload had better musculoskeletal capacity compared to the men with high workload. Among the subjects with low workload both the declines and improvements were more common than among the subjects with high workload.

There were differences in physical capacity among workers with different workloads depending on how the workload was assessed (subjectively or objectively), especially among men. Among women the differences in physical capacity between different workload groups were minor independent of the workload assessment method. Instead among men, who perceived high workload but were objectively assessed to have low workload had poorer muscle strength than those men whose workload was the same regardless of assessment method.

It was concluded that there are age-related decline in physical capacity. The annual changes in physical capacity were dependent on the different components of physical capacity. Improvements in physical capacity compared with subjects of the same age were also noted. In addition there seem to be differences in physical capacity in relation to workload. However, the workload assessment method (objectively or subjectively assessed) was associated with the differences in physical capacity between workers with different workloads, especially among men. It also has to be considered that a worker with poor physical capacity may perceive his/her physical workload as high although he/she has as objectively assessed physically low workload. These results permit the conclusion that physically demanding work may not maintain or improve physical capacity among ageing workers. To avoid increased relative workloads among elderly workers it is necessary to reduce the work demands imposed on elderly workers and / or maintain or improve their physical capacity.

Tiivistelmä

Terveys ja toimintakyky muodostavat perusedellytykset ihmisen voimavaroille ja hänen työkyvylleen. Aikaisempien tutkimusten perusteella on saatu hyvin erilaisia tuloksia siitä, miten fyysinen toimintakyky muuttuu ikääntyessä. Fyysisen toimintakyvyn muutoksiin vaikuttavat sukupuoli, fyysinen aktiivisuus, krooniset sairaudet, lihasryhmä ja lihastyötapa (staattinen vai dynaaminen). Tämän lisäksi myös yleisellä työn kuormittavuudella on oma merkityksensä joko toimintakykyä harjoittavana tai kuluttavana tekijänä.

Tämän tutkimuksen tarkoituksena oli tarkastella tuki- ja liikuntaelimistön sekä sydän- ja verenkiertoelimistön toimintakyvyn muutoksia ikääntyessä suhteessa erilaiseen työn kuormitukseen pitkän seuranta-ajan aikana. Toisena tavoitteena oli selvittää, onko työn kuormituksen arviointimenetelmällä yhteyttä eri työn kuormittavuusryhmien välillä mahdollisesti esiintyviin fyysisen toimintakyvyn eroihin.

Tietoja kerättiin fyysisen toimintakyvyn mittauksilla laboratoriossa, kenttätutkimuksilla työssä ja postikyselyillä. Ensimmäinen tutkimusaineisto koostui 129 keski-ikäisestä joko henkistä tai fyysistä tai henkis-fyysistä työtä tekevästä kunta-alan työntekijästä, joita seurattiin 16 vuotta. Seurannan alussa he olivat keskimäärin 51.5 vuotiaita ja kaikki olivat mukana työelämässä. Seurannan lopussa henkilöiden keski-ikä oli 67.3 vuotta, jolloin lähes kaikki olivat jo eläkkeellä. Toinen tutkimusaineisto koostui 60 samassa elintarviketehtaassa fyysisesti raskaassa työssä olevista naisista, joiden keski-ikä oli 52.3 vuotta seurannan alussa. Seurannan lopussa heidän keski-ikänsä oli 62.9 vuotta.

Yleisesti ottaen tutkimuksessa havaittiin ikään liittyvää fyysisen toimintakyvyn laskua. Seurannan aikana fyysinen toimintakyky laski keskimäärin 1.0 % vuodessa. Miehillä eniten heikkenemistä havaittiin puristusvoimassa ja vartalon lihasvoimissa, kun taas naisilla eniten muutoksia esiintyi selkärangan liikkuvuudessa, vartalon ojennusvoimissa, ylä- ja alaraajojen kestävyysvoimassa sekä painoon suhteutetussa hapenkulutuksessa. Pienimpiä muutokset olivat antropometriassa. Miesten muutokset fyysisessä toimintakyvyssä olivat suurempia kuin naisten, mutta naisilla esiintyi enemmän yksilöllisiä vaihteluita.

Naisten väliset erot fyysisessä toimintakyvyssä eri työn kuormitusmuotojen välillä olivat selkeämpiä kuin miesten vastaavat erot. Naisilla, joiden työn kuormittavuus oli alhainen, oli parempi toimintakyky seurannan lopussa kuin naisilla, joilla työn kuormitus oli korkea. Kun taas miehillä, joilla oli alhainen työn kuormitus, oli parempi tuki- ja liikuntaelimistön toimintakyky verrattuna miehiin, joilla oli korkea työn kuormitus.

Suhteessa samanikäisiin fyysisen toimintakyvyn paraneminen ja heikkeneminen olivat yleisempiä kevyen työn tekijöillä kuin henkilöillä, joilla oli raskas työ.

Lisäksi fyysisessä toimintakyvyssä esiintyi eroja sen mukaan, kuinka työn kuormittavuutta oli arvioitu (subjektiivisesti vai objektiivisesti) etenkin miehillä. Naisilla erot fyysisessä toimintakyvyssä eri työn kuormitusryhmien välillä, kun huomioitiin arviointimenetelmä, olivat vähäisiä. Sen sijaan miehillä, jotka kokivat työnsä raskaaksi, mutta joilla objektiivisesti arvioituna oli alhainen työn kuormittavuus, oli huonompi lihasvoima kuin niillä, joiden työn kuormittavuusluokka pysyi samana arviointimetelmästä riippumatta.

Tulosten perusteella voidaan päätellä, että fyysinen toimintakyky heikkeni ikääntyessä, mutta myös toimintakyvyn paranemista suhteessa samanikäisiin tapahtui. Toimintakyvyn muutosten suuruus riippui tarkasteltavasta osa-alueesta. Lisäksi fyysisessä toimintakyvyssä esiintyi eroja eri työn kuormitusryhmien välillä. Toisaalta erot fyysisessä toimintakyvyssä riippuivat myös siitä, mitä työn kuormittavuuden arviointimenetelmää oli käytetty. Pitää myös huomioida, että työntekijä, jolla on huono fyysinen toimintakyky, saattaa kokea työnsä fyysisesti raskaaksi, vaikka objektiivisesti arvioituna hänen työnsä olisi fyysisesti kevyttä. Saatujen tulosten perusteella voidaan todeta, että fyysinen työ ei ylläpidä tai paranna fyysistä toimintakykyä ikääntyvillä työntekijöillä. Jotta ikääntyvien työntekijöiden työn kuormitusta saadaan vähennettyä, niin työn vaatimuksia pitäisi laskea suhteessa fyysiseen toimintakykyyn ja/tai parantaa heidän fyysistä toimintakykyään.

1 Introduction

The ageing of the population is both a great challenge and threat for most modern societies all over the world. The EU countries will have the oldest work force in their histories; in the near future, between 2005 and 2015, the mean age of the work force will rise to over 45 years of age. (Ilmarinen 1999.) At the same time the risks of disability and need for its prevention are increasing.

The health of older workers is a concern to the extent that the productivity of older workers is considered to be a function of age-related health, the general conclusion being that age-related declines in health inevitably lead to decreased productivity (Robertson and Tracy 1998). In addition the aerobic demands and exposures in work life of today remain high. These high demands and exposures are reflected in a mismatch between workers' physical capacity and the physical demands of work. (Karlqvist et al. 2003a.)

Health and functional capacities form the basis for human resources and working ability (Ilmarinen 2001). Functional capacity subsumes social, mental and physical components. Physical capacity includes anatomical and physiological factors (aerobic capacity, muscle strength, flexibility of joints), which are affected by individual, neurological and psychological factors like age, disorders and motivation.

Previous studies have yielded inconsistent results of varying levels regarding changes in physical capacity with age (e.g. Era and Rantanen 1997, Metter et al. 1997, Rantanen et al. 1997, Baumgartner et al. 1999, Giampaoli et al. 1999). The changes in physical capacity depend on age, gender, physical activity level, chronic diseases and disorders (e. g. Rantanen et al. 1998, Kasch et al. 1999, Paterson et al. 1999). However, one of the most important factors affecting the change, is which component of physical capacity is studied. Moreover, the type of job may be of great importance for either training or wearing effect on the implicated physical capacity (Schibye et al. 2001).

There are many studies on the relations between workload and workers' various disorders (e.g. Hoogendoorn et al. 1999, Hansson et al. 2000, Roquelaure et al. 2000). However, to the author's knowledge there are no longitudinal studies on changes in physical capacity among ageing subjects who have been compared with same age subjects at similar workloads and how these changes are related to workload. In addition, the measurements are usually incomplete, covering only either one component of musculoskeletal or cardiovascular capacity (flexibility of joints, muscle strength or aerobic capacity), one muscle group or one type of muscle work. The main purpose of this study was to ascertain changes in musculoskeletal and cardiovascular capacity in relation to different workloads among the same subjects during the long follow-up period. The second aim was to find out if there are differences in physical capacity between workload groups depending on the workload assessment method.

2 Review of the literature

The relation between physical capacity and work during ageing is multidimensional and it is not possible to take into account all the factors affecting this relation. In this study physical capacity and the physical demands of work are considered. The association between physical capacity and workload during ageing has been considered on the basis of the conceptual model of work ability (Ilmarinen 1999), which has been modified for the purposes of the present study. (Figure 1)

2.1 Working life and ageing

2.1.1 Changes in working life

In recent decades the work environment and type of work have changed. A feature of present day work environments is that workers are increasingly interacting with some form of technology and are frequently required to monitor automated and semi-automated systems over extended vigilance tasks. This trend can be seen in the transport, power and manufacturing industries, as well as in the health care sector. (Bunce and Sisa 2002.) Furthermore, it has been suggested that the industrial developments have resulted in a decreasing number of occupations that are physically strenuous in the traditional sense of the word, i.e. demanding intensive dynamic work with large muscle groups (Aminoff et al. 1999). However, it has been emphasised that 27% of men and 22% of women are still required to do work that exceeds their individual aerobic capacity (Karlqvist et al. 2003b). In addition, in the study by Karlqvist et al. (2003b) was indicated that physical fitness was low or somewhat low for two-thirds of men and for more than one-half of women. On the other hand, many jobs have become stationary and use only one side of the body thus imposing static, combined static / dynamic and asymmetric loads, especially on the arm-shoulder area (Aminoff et al. 1999). Additionally, it has been found that the share of white-collar work has increased and physical loads decreased among men between 1973 and 1997 but among women the loads have remained unchanged or increased and the share of blue-collar work has increased (Torgèn and Kilbom 2000). On the other hand, in a Finnish longitudinal study the workers reported that the physical and mental demands of their jobs had mainly increased between 1981 and 1992, especially muscular work and use of knowledge. Considering three different work categories (physical, mental or mixed physical and mental work) more men in the mental group and more women in the mixed group reported an increase in muscular demands than in the other work groups. (Nygård et al. 1997.)

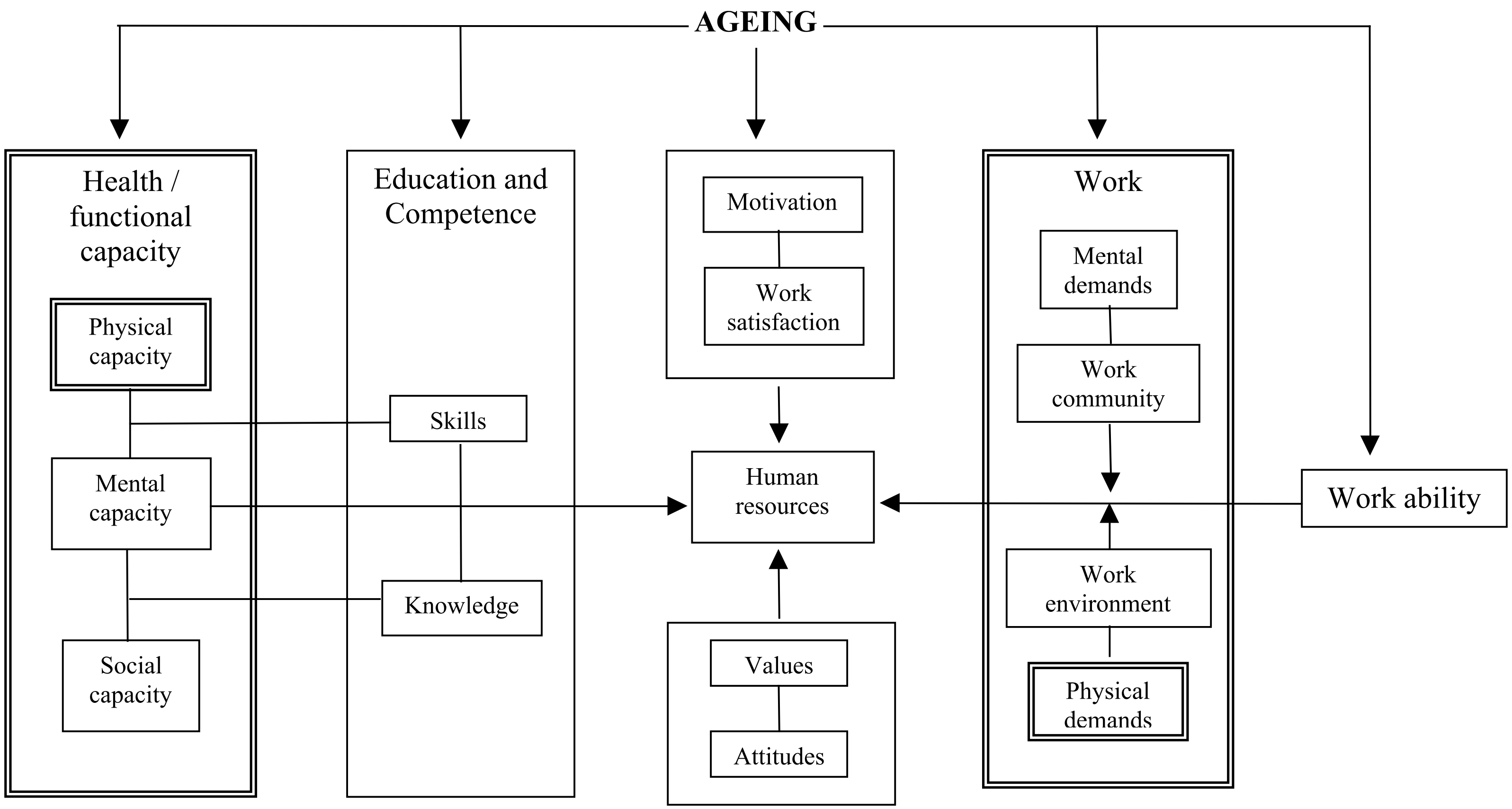

Figure 1 The frame of the study (the conceptual model of work ability as modified from Ilmarinen 1999)

2.1.2 Ageing of the work force

In addition to the changes in working life, there have also been changes within working populations. With the advent of ageing populations and a decline in birth rates, the industrialized societies of the advanced nations are experiencing a marked decline in the working-age population (Kumashiro 2000). At the same time the average age of workers is rising in most countries (Shephard 2000). The term ‘active ageing’ is in common use and calls on corporations to make major changes in current practices in order to accommodate the ageing worker. In general, when companies evaluate the effect of worker ageing on the workplace, they tend to regard the decline of physiological functions accompanying ageing as handicap factors. (Kumashiro 2000.)

However, ageing may lead to deterioration in self-image, particularly if the worker believes that his/her physical or technical skills are no longer adequate for the task. An age-related loss of physical capacity is an important concern for those in very heavy jobs. If function becomes marginal relative to task demands, the rate of production will diminish in self-paced work, and in machine-paced tasks excessive fatigue may lead not only to a poor quality of work and industrial accidents, but also to a sense of poor overall health. The latter may manifest itself in industrial disputes, injuries, absenteeism, a high employee turnover rate and early retirement. (Shephard 2000.)

Besides the fact that physical capacity decreases with age, it is very important to remember that the ageing worker has plenty of synergistic capacity. Synergistic capacity has been described as a general capacity to perform tasks supported by a wealth of experience and knowledge. It is important that this synergistic capacity is utilized to the maximum extent possible to provide adequate support for declining physical capacity. (Kumashiro 2000.)

2.2 Physical capacity and ageing

Physical capacity includes anatomical and physiological factors (aerobic capacity, muscle strength and flexibility of joints), which are affected by individual (e.g. gender, body structure), neurological and psychological factors. Age related changes affect all these components of physical capacity in different ways.

A decrease in physical capacity can be noted around the age of 30, followed by continued small decrements until about the age of 50 years, when changes become more rapid. In general, among women the relative declines in physical capacity are smaller than among men due to lower maximal levels of physical capacity at younger ages. (Stamford 1988, Metter et al. 1997, Samson et al. 2000.)

In addition to age and gender, the changes in physical capacity are depending on chronic diseases, disorders (Baumgartner et al. 1999) and physical activity level (Trappe et al. 1996, Pollock et al. 1997, Kasch et al. 1999, Paterson et al. 1999). One of the most important factors affecting the change is which component of physical capacity is studied. Moreover, the type of job may be of great importance for either training or wearing effect on the physical capacity implicated (Schibye et al. 2001).

2.2.1 Anthropometrics

Anthropometrics subsumes the height, weight, body mass index and fat percentage of the person. In general changes in anthropometrics are related to ageing (Sagiv et al. 2000) and changes in training habits (Pollock et al. 1997).

Height

It has been reported that decline in height does not occur before the age of 40, but the rate of decline increases at a later age (Lynch et al. 1999, Sagiv et al. 2000). An age-related reduction in height from the young adults became apparent for men in their 70s and for women in their 60s. (Lynch et al. 1999.) The change of the human body's stature is mainly a result of changes in the spinal vertebral bodies and disk spaces. The height of the vertebral body is mineral related, while the height of disk space is related to the fibrocartilage quality of the annulus fibrosus and hydration level of the nucleus pulposus. Thus, when a person gets older, a reduction in vertebral body and disk space heights can be seen. Generally, height loss was about 0.1% per year. (Sagiv et al. 2000.) The average loss of height from age 20 to ages 65–75 years was 4 cm, and it was 7.5 cm by ages 85–94 years. Men lose 3% of bone mass per decade, while women after the menopause may lose up to 8%. (Siegel 1984.) Females' height loss rate was significantly higher than that of the males, which suggests that the stature of women is affected more than that of men by the ageing process (Sagiv et al. 2000).

There are dissimilar results concerning the relationship between ageing, height and physical activity. Positive relationship has been reported between physical activity and attenuation of height loss due to ageing that was higher in males than women. This relationship can be explained by a reduction of the rate of bone density loss, which in turn, will avoid compression of the vertebrae and, hence, lead to slower stature decline in males and females. Another possible mechanism can be that physical activity may reduce the rate of bone density loss and / or slow the pace of the cartilaginous tissue degeneration in the disk spaces between vertebrae. (Sagiv et al. 2000.) On the other hand Eskurza et al. (2002) and Tanaka et al. (1997) did not find any significant difference in height loss between ageing sedentary and trained people.

Weight

There are discrepancies between different studies concerning body weight and ageing. It has been observed that body weight increased in a quadratic trend upwards across age groups (Hunter et al. 2000). It has also been proposed that body mass was significantly lower in the oldest decade than in young adults among the men. However, there were no differences in body mass in women across the adult life span. (Lynch et al. 1999, Paterson et al. 1999.) Furthermore, according to the study by Bassey (1998) body weight decreased 0.3% per year among men and 0.5% per year among women.

There are many reasons for these changes in weight when ageing. A low relative metabolic rate may be one reason for weight gain. Absolute basal metabolic rate was significantly lower in older subjects compared with the young subjects and in the women compared to men. Because catecholamines stimulate cellular metabolism, it is conceivable that changes in the sympathetic nervous system activity may in part explain the reduction in metabolic rate that occurs with ageing. (Piers et al. 1998.) On the other hand the decline in weight when ageing particularly reflects loss of muscle mass and its partial replacement by fat and connective tissue. A decline of 3% to 5% in muscle mass per decade occurs after the age of 30 years, with a more accelerated loss after 60 years. (Hamerman 1998.) The loss in whole body muscle mass is greater in men than in women, both on an absolute basis and relative to body mass (Janssen et al. 2000).

Age-related loss of muscle mass occurs in relatively healthy, well-nourished elderly men and women and has a multifactorial basis. Decreased physical activity, hormones, malnutrition and chronic disease have been identified as factors contributing to this loss. (Baumgartner et al. 1999.) Among trained people body weight remained stable (Pollock et al. 1997, Tanaka et al. 1997) whereas among sedentary men (Pimentel et al. 2003) and women (Tanaka et al. 1997) body weight increased with age.

Body mass index

It has been reported that body mass index (BMI) increased across age groups in a linear trend (Piers et al. 1998, Hunter et al. 2000). On the other hand it has also been suggested that body mass index did not differ significantly by age in either men or women (Lindle et al. 1997). In addition it has been found that men had a significantly higher body mass index than women during ageing (Lindle et al. 1997, Piers at al. 1998). The larger BMI gains in men are caused by a larger relative increase of fat-free mass in the men (Trudeau et al. 2001). It has also been proposed that there is no significant difference in BMI between the genders (Era et al. 2001). However, no significant differences in BMI between the relatively active and inactive subjects have been observed (Hunter et al. 2000, Eskurza et al. 2002) and among obese subjects. Instead, among people with normal BMI, age-dependent increase in BMI was noted (Miyatake et al. 2000).

Fat percentage

In men, percent body fat showed a significant increase beginning in the 50s, and in women it was significantly higher than in the young adults in the 40s, 50s, and 60s (Gallagher et al. 1996, Lynch et al. 1999). However, men had significantly higher total body fat free mass and lower fat percentage than women (Lindle et al. 1997). In general, men showed larger gains of abdominal skin-folds, whereas women had larger gains in the triceps skin-fold. Increase in the sum of four skin-folds did not differ significantly between men and women. (Trudeau et al. 2001.) Overall, physical activity has significant positive correlations with muscle mass and negative correlations with body fat both among men and women (Baumgartner et al. 1999).

Active subjects had significantly less estimated body fat and greater amounts of estimated lean body mass than inactive subjects (Hunter et al. 2000). Fat free mass decreased and body fat percentage increased among both sedentary and endurance-trained people with age (Eskurza et al. 2002, Pimentel et al. 2003). However, it has been suggested that body fat percent increased with age in sedentary and active men, whereas no change was observed in endurance-trained men (Wilson and Tanaka 2000). In addition, in sedentary women, no significant relations were observed between age and fat free mass, whereas body fat percent increased with advancing age. In the endurance-trained women, fat free mass did not decline with age, whereas body fat percent was positively related to age. (Tanaka et al. 1997.)

2.2.2 Muscle strength

The factors affecting muscle strength can be categorised in many ways. Bäckman et al. (1995) have divided these factors into nervous, muscular and biomechanical factors. The nervous factors include degree of cooperation, motivation, and ability to activate motor units, and to do so with optimal frequency. The muscular factor is related to the amount of contractile proteins. This means that strength is correlated to the muscle fibre area or approximatively the muscle cross-section area. Among the biomechanical factors, the positions of the extremities, as well as of the subjects, and the length of levers used are important. (Bäckman et al. 1995.) In this study the factors have been divided into individual, anatomical or physiological factors. (Figure 2 factors in bold face are considered in this study.)

There are many anatomical factors affecting changes in muscle strength during ageing. Muscle volume, maximum anatomical cross sectional area and fibre fascicle length were all significantly reduced in the older individuals (70–81 years) compared to the younger adults (27–42 years) (Narici et al. 2003). Furthermore, it has been concluded that quantitative loss in muscle cross-sectional area is a major contributor to the decrease in muscle strength seen with advancing age and, together with earlier muscle strength, accounts for 90% of the variability in the strength in the future (Frontera et al. 2000). The decline in fat-free mass particularly reflects loss of muscle mass and its partial replacement by fat and connective tissue. A decline of 0.3% to 0.5% in muscle mass per year occurs after the age of 30 years, with a more accelerated loss after 60 years. There is a parallel decrease in muscle strength that occurs with ageing, reaching almost 3% per year after 70 years. (Hamerman 1998.) The mechanism responsible for reduced muscle strength per unit of muscle mass is not understood, but

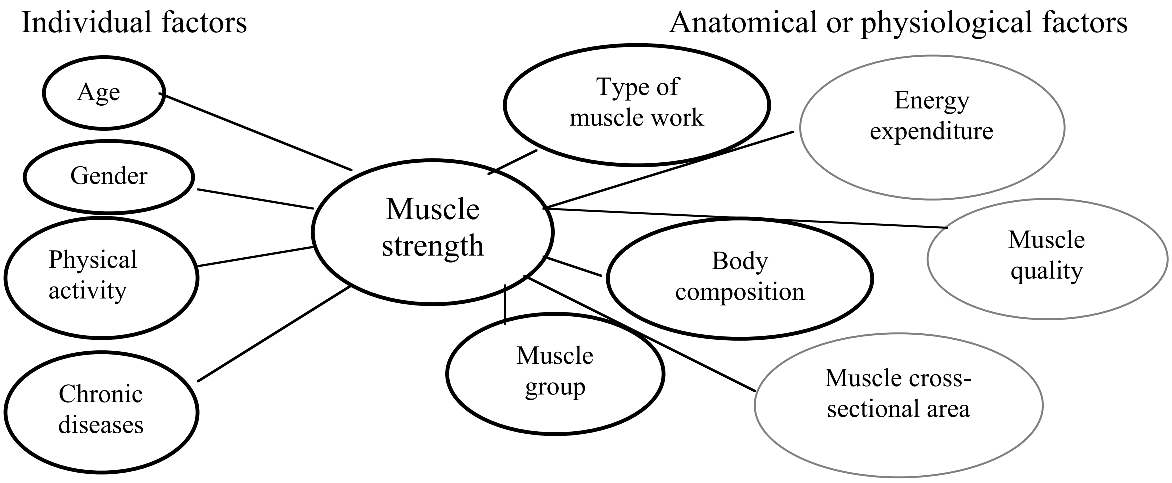

Figure 2. Factors in relation to muscle strength during ageing

nevertheless the reduction is likely to be due to changes in muscle structure, muscle protein synthesis and composition (Basu et al. 2002). An alternative explanation for the inverse association of age muscle strength independent of muscle mass might be that changes in strength are not linearly related to changes in muscle mass. Additionally, changes in muscle function (strength) may occur more rapidly with age than measurable changes in muscle mass. (Baumgartner et al. 1999.)

Reduction in muscle strength is determined by not only a decrease in muscle mass but is also due to changes in muscle fibres. It has been suggested that muscle atrophy is a result of a reduction in the number of muscle fibres (Frontera et al. 2000) and that the size of muscle fibres is reduced with advancing age (Hamerman 1998, Basu et al. 2002). It has been speculated that reduced size of muscle fibres is likely due to a predominantly neurogenic process involving progressive loss of motor units. It is not known, however, whether this is due to disuse, disease or inherent in the ageing process. The type I (slow twitch) fibre type is much less, if at all affected by the ageing process compared to fibre type II. Loss of muscle fibre number in turn leads to loss of muscle volume as well. (Basu et al. 2002.)

There are still other minor factors pertaining to changes in muscle strength in ageing. One may be the age-related decrease in muscle metabolic capacity, which is apparent as early as between the 3rd and 5th decades of age and is independent of variations in activity-related energy expenditure. (Hunter et al. 2002.) In addition, the circulatory mediators e.g. hormones, growth factors, inflammatory factors, and protein synthesis activators also contribute to the loss in strength by their actions on muscle to maintain and alter homeostasis. Age losses have been reported in growth hormone, testosterone and others which appear to be general controllers responsible for maintenance of the muscle. (Metter et al. 1997.)

In general, annual decline in muscle strength ranges from 0.8% to 5% depending on age, gender, muscle group, type of muscle work (dynamic or static), physical activity and chronic disease (Nygård et al. 1991, Lindle et al. 1997, Bassey 1998, Frontera et al. 2000, Samson et al. 2000).

2.2.2.1 Gender

In general women have lower muscle strength than men. At all ages, women have only about 52–86% of male strength, depending on muscle group (Bäckman et al. 1995, Bassey 1998, Shephard 1999). For men, significant age differences were found in strength with peaking in the 30s and then a steady decline. In women strength declined with age and the changes beginning in the 50s decade. Strength declined 34% in men and 32% in women from 20-year-olds to 80-year-olds. Both longitudinal and cross-sectional data for women exhibited a less clearer age-associated loss of strength than for men. (Metter et al. 1997.)

Women had a body weight of 76–86% of the men, but the variations in strength between persons in the same age group cannot only be explained by differences in weight. Besides, the correlations between weight and muscle strength in different muscle groups have been low. (Bäckman et al. 1995.) However, it has been noted that grip and leg strength was better in obese (BMI $\geq$ 26.4) subjects than non-obese subjects under the age of 60 in both genders. Instead, in subjects over 60 years old, muscle strength was similar between obese and non-obese subjects. Nevertheless, relative muscle strength adjusted to body weight was significantly lower in obese subjects than in non-obese subjects. (Miyatake et al. 2000.) In addition, an association has been found between age-related loss of muscle strength and change of body composition (Bassey 1998, Miyatake et al. 2000).

The underlying etiology of the age-related losses of muscle mass and strength differs between men and women. In men, 57% of the variance in muscle mass was explained by knee height, free-testosterone, physical activity, coronary heart disease or cardiovascular disease and insulin-like growth factor 1(IGF1) in men. Whereas in women, knee height, total body fat mass and physical activity explained together 52% of the variance in muscle mass. (Baumgartner et al. 1999.) Furthermore, body height and weight were significantly correlated with skeletal muscle in both men and women. Taller subjects have longer bones and muscles and would be expected to have a greater muscle mass. Indeed, the greater the body weight, the smaller the increase in skeletal muscle mass. Increased weight favoured a proportionately larger increase in lower body muscle. The loss in whole body muscle mass was independent of change in stature and was greater in men than in women, both on an absolute basis and relative to body mass. Height and weight explained about 50% of the variance in skeletal muscle mass in men and women. (Janssen et al. 2000.)

Men had significantly more skeletal muscle in comparison to women both in absolute terms (33.0 vs. 21.0 kg) and relative to body mass (38.4 vs. 30.6%). The gender differences were greater in the upper (40%) than lower body (33%). These differences remained significant after controlling for height and body mass. In comparison to women, men had a significantly greater percentage of total skeletal muscle mass in the upper body (42.9% vs. 39.7%) and a lower percentage of total skeletal muscle mass in the lower body (54.9% vs. 57.7%). (Janssen et al. 2000.)

A reduction in relative skeletal muscle mass starting in the third decade is seen. However, no noticeable decrease in absolute skeletal muscle mass was observed until the end of the fifth decade. (Miller et al. 1993, Janssen et al. 2000.) Men had significantly less arm and leg muscle mass in the 60s and older decades. However, arm muscle mass was significantly lower in their 60s and older decades in women, while leg muscle mass reductions began as early as the 40s. (Lynch et al. 1999.) Among men, age was significantly related to lower body but not upper body skeletal muscle. Among women, age was related to both lower body and upper body skeletal muscle. (Miller et al. 1993, Janssen et al. 2000.)

The difference between arm and leg muscle quality (= specific tension, referring to strength per unit of muscle mass) was unchanged with age in men but increased in women, indicating that leg muscle quality declined more with advancing age than arm muscle quality in women. This suggests that in women the arm muscles may not experience as much age-related change in contractile properties, connective tissue, or architectural components as leg muscles. (Lynch et al. 1999.)

Moreover, declining endocrine function may be playing a relatively more important role than physical inactivity or "disuse atrophy" in muscle loss in elderly men. In contrast to men, age-related differences in hormones did not appear to be important factors associated with muscle mass in women. The effects of body fat and physical activity were independent and additive, indicating that sedentary women with low body fat had the least muscle mass regardless of age or body size. (Baumgartner et al. 1999.)

2.2.2.2 Muscle group and type of muscle work

The discrepancy at the beginning of the changes in muscle strength when ageing may be a result of the range of muscles tested and the varying degrees of disuse specific to individual muscle groups and / or the populations studied. The physical activity level of the sample group has been thought to be a potential confounding factor in defining strength decrements across age groups. The strength of a single muscle group cannot be taken as indicative of the status of all the muscles of an individual. The magnitude and the rate of strength decrement across the age groups were specific to the muscle group assessed. (Hunter et al. 2000.) There is a greater reduction in the thigh muscle area than in either the calf or arm muscle, emphasizing the importance of site location, and in addition, age, gender and previous exercise history in assessing muscle strength (Hamerman 1998).

Ageing-related decline in muscle function is more apparent in locomotor muscles than in non-locomotor muscles (Landers et al. 2001). It has been reported that the reason for this difference between muscle groups was not decreased skeletal muscle oxidative capacity. The older men and women had no deficit in oxidative capacity compared with their younger counterparts. (Kent-Braun and Ng 2000.) In addition, structural abnormalities occurring with age and affecting force production may be more easily recognized in pinnate versus fusiform muscle. The result of age-related changes in neural stimulation possibly affecting the size and shape of muscle fibres, may therefore have a more pronounced effect on force production by the knee extensors (pinnate muscle) compared with elbow flexors (fusiform muscle). (Landers et al. 2001.)

In a Swedish cross-sectional study, on men aged 17–70 years was noted that in all the muscle groups the weakest muscle strength was found in the oldest age group. However, no significant changes of strength throughout the age groups were found in the elbow flexors, ankle dorsal flexors, or shoulder abductors. In the hip abductors, the only significant difference was found between the youngest (17–18 year) and the oldest (60–70 year) age groups. In addition the values of hand grip strength showed no significant differences between different age groups. The highest values were found in age group 30–39 years old. (Bäckman et al. 1995.) Moreover, Nevill and Holder (2000) showed that handgrip strength peaked in the age group 25–34 years for male subjects and in the age group 35–44 years for female subjects. Furthermore, in a longitudinal study it was found that among men of 71 years and over, 22% increased or maintained their previous handgrip strength level. However, over the entire 27 year follow-up period only 1.1% of the survivors showed no strength decrease. It is worth noting that grip strength is a relatively stable characteristic, which indicates that over 30% of the variation in grip strength measured in old age is explained by midlife strength. (Rantanen et al. 1998.)

It has been suggested that the reductions in strength of handgrip and the plantar flexors across age groups was curvilinear in trend, with a relative preservation of strength before a more rapid decline in women aged 50 years and over. The knee extensors showed the most consistent and rapid decline in strength across the age groups from 25 years of age on. The relative preservation of the handgrip and plantar flexors' strength in the middle years of life compared with the knee extensors may be due to varying degrees of muscle group use and / or their fibre-type composition. (Hunter et al. 2000.) In general, limb muscles in older men and women are 25–35% smaller and have significantly more fat and connective tissue than limb muscles in younger individuals (Lexell 1995). It is well documented that the relative strength difference between younger and older women was greater in the legs than in the arms despite an almost identical difference in arm and leg lean tissue. The older women had 15% and 14% less lean tissue mass in the legs and arms respectively, and 23% and 10% less strength in the knee extensors and elbow flexors compared with the younger women. (Landers et al. 2001.)

Muscle mass may be more important in explaining arm strength loss than leg strength loss (Lynch et al. 1999, Landers et al. 2001). It has been noted that arm and leg muscle quality declined at a similar rate with age in men, whereas leg muscle quality declined about 20% more than arm muscle quality with increasing age in women. However, muscle quality of the arm was significantly higher than muscle quality of the leg across the entire life span in both genders. Thus more strength is produced per unit of muscle mass in the arm than in the leg in men and women. (Lynch et al. 1999.) Another plausible explanation for the difference between arm and leg strength loss may be a disproportionate atrophy of type II muscle fibres. Type I muscle fibres are the primary fibre used for the maintenance of posture and slow, low-intensity movements. A change in the size of type II muscle fibres would decrease the strength-to-cross-sectional area ratio. (Landers at al. 2001.) Although no other age-related factors to explain this difference have been identified, possible mechanisms include neural activation differences between the arm and leg (Lynch et al. 1999).

In addition to age, lean body mass, level of physical activity, height and the estimated cross-sectional area of muscle and bone have been the best explanatory factors for the variation in limb muscle strength (knee extensors, plantar flexors, handgrip) (Hunter et al. 2000). Moreover, in the study by Baumgartner et al. (1999) it was noted that muscle mass and age explained 43% and 35% of the total variance in grip strength among men and women respectively. The linear association between height and grip strength and non-linear association between body mass and grip strength have been identified. Handgrip strength increased with body mass until it peaked at a body mass of approximately 100 kg for male and 90 kg for female subjects; thereafter a rapid decline in grip strength was observed. (Nevill and Holder 2000.) Furthermore, it has been observed that together with baseline grip strength, subjects' age, height and waist circumference predicted 52% of the variance of grip strength at follow-up. It was found that 83% of the stable variation in hand-grip strength was due to persistence of genetic and shared familial influences from middle age to old age. A decrease in genetic variance from 35% at baseline to 22% at follow-up was also observed, likewise a slight increase in shared environmental influences (training and learned behaviours associated with muscle use) from 39 to 45%. (Carmelli and Reed 2000.)

Annual declines with age are different in different muscle groups. According to the follow-up studies the annual decrease in trunk flexor strength was 1.1–2.2%, trunk extensors 1.7–1.8% and in upper limb 1.3% among men (Nygård et al. 1991, Sörensen et al. 2000). Among women the trunk flexion and extension strength decreased 0.8% and 0.9%, respectively. (Nygård et al. 1991.) Significant losses in the knee extensors of 0.9–2.5% per year and knee flexors 2.4–2.5% per year have been observed depending on angular velocities (Frontera et al. 2000, Hunter et al. 2000). Corresponding, the loss of elbow extensor strength was 0.8–1.6% per year and of flexor strength 1.4–2.2% per year. (Frontera et al. 2000.) The linear reductions in plantar flexors and handgrip strength with age have been shown. The annual decline in plantar flexors was 0.7%. (Hunter et al. 2000.) Instead, in handgrip strength an annual decrease of 0.3–1.6% has been observed among men and 0.6–2.2% among women (Bassey 1998, Hunter et al. 2000, Mokdad 2002).

However, according to the model by Nevill and Holder (2000) the changes in muscle strength were not linear across age. The model predicted that the rate of decline in handgrip strength for 60- and 70-year-old male subjects is approximately –1.0% and –1.5% per annum respectively. Similarly, the model predicts that the rate of decline is approximately –1.1% and –1.6% for 60 and 70-year-old female subjects respectively. Instead, for 80-year-old male and female the model predicts rates of decline in handgrip strength of –1.9% and –2.1% per year. (Nevill and Holder 2000.)

In addition to muscle group, limb muscle strength has also been found to be associated with limb dominance and activity in women aged 20 to 89 years. The effect of dominance was greatest in handgrip compared with the knee extensors and the plantar flexors. (Hunter et al. 2000.) The values of strength of the non-dominant side were considered to be less dependent on motor skill than on the dominant side (Bäckman et al. 1995). The small difference in limb dominance strength for all muscle groups may have minimal functional consequences for an individual, particularly in comparison with the effect of age and physical activity (Hunter et al. 2000).

The changes in muscle strength are also dependent on the type of muscle work; dynamic (concentric or eccentric) or static. Both men and women exhibit age-related declines in isometric and concentric strength starting in the fourth decade at a rate of about 0.8–1.0% per year. The age-related decline for eccentric strength is about the same for men and women, but women appear to start their decline at least a decade later. The men showed almost identical declines in concentric compared with eccentric strength, whereas women showed more of a difference between concentric and eccentric losses with age. For some undetermined reason, women tend to preserve their eccentric strength levels with age much better than men do. (Basu et al. 2002.) However, it has been shown that age explained losses in concentric better than eccentric peak torque in both genders (Lindle et al. 1997, Lynch et al. 1999).

It has been proposed that the steadiness of isometric contractions among old adults was reduced compared with young adults, but not during concentric and eccentric contractions with the knee extensor muscles. Old subjects also used greater coactivation of an antagonist muscle during both types of contractions. The maximal voluntary contraction force of the knee extension for the old subjects was 33% less than that for the young subjects. Within genders, the age differences were similar. The reductions in anisometric strength were not significantly different from those with maximum voluntary contractions force, with a 42% decrease in one repetition maximum load for the old subjects compared with the young subjects. (Tracy and Enoka 2002.)

In a cross-sectional study a significant inverse correlation was observed between age and isometric strength of both the knee extensors and elbow flexors (Landers et al. 2001). The average isometric strength of limbs for women was about 70% (range 52–91%) that of men in all age groups. For hand grip strength, the results for women were about 65% that of men in all age groups except the youngest and the oldest, where the women had respectively only 58 and 55% of the strength of the men. (Bäckman et al. 1995.) For the maximal isometric trunk flexors and extensors strength the women's strength was respectively 67 and 69% of men's (Nygård et al. 1991).

2.2.2.3 Physical activity and chronic diseases

Physical activity scores had significant positive correlations with muscle mass both in the men and women (Baumgartner et al. 1999). In general, self-reported physical activity levels declined with age but women who were more physically active for their age group were stronger in all muscle groups and had more lean body mass and lean thigh and leg cross-sectional area than relatively inactive women. The active women were significantly stronger than the inactive women when absolute strength of the leg muscles was normalized for body weight and normalized for lean body mass (knee extensors, plantar flexors and handgrip). However, the linear downward slope with age in lean mass cross-sectional area was similar for both active and inactive subjects. (Hunter et al. 2000.)

A reduction in physical activity would primarily be associated with a decreased use of lower body muscles, but not upper muscles, given that the muscles in the lower body are required for most common activities (i.e. walking, stair climbing) (Janssen et al. 2000). Differences in handgrip strength were found to be significantly associated with levels of physical activity, but the association observed was not linear. The level of physical activity necessary to maintain an optimal level of handgrip strength was found to be a balance of moderate to vigorous occasions of physical activity. The most obvious explanation is that physical activity prevents or reduces the age-related loss of muscle and consequent decrease in strength. (Nevill and Holder 2000.)

Various diseases and disorders have also to be accounted for when muscle strength and ageing are considered. The central nervous and neuromuscular systems change with age, so rapid and continuous movements are slower at any workload in older subjects. It has been reported that men with coronary heart disease or cardiovascular disease had significantly less muscle mass and lower serum sex-hormone binding globulin than men without these diseases. However, there was no difference between men with and without coronary heart disease or cardiovascular disease for grip strength. Moreover, women with coronary heart disease or cardiovascular disease had significantly lower physical activity scores than those without these diseases, but there were no differences for muscle mass or grip strength. (Baumgartner et al. 1999.) On the other hand, in a longitudinal study it was observed that steeper than average annual decline in handgrip strength (over 1.5% per year) was associated with older age at baseline, greater weight decrease and chronic conditions such as stroke, diabetes, arthritis, coronary heart disease and chronic obstructive pulmonary disease. (Rantanen et al. 1998.) Instead, in another study it was noted that only musculoskeletal problems were found to correlate significantly with strength when controlling for age and sex. The implication is that in otherwise healthy individuals, the presence of some chronic diseases does not adversely affect their ability to maintain the normal strength of their age. (Metter et al. 1997.)

2.2.3 Aerobic capacity

The ability of the human body to do heavy sustained work has most often been described in terms of aerobic capacity (Era et al. 2001). Maximum oxygen uptake is defined as the highest rate at which oxygen can be taken up and utilized by the body during strenuous exercise. There are clear physiological factors that could limit aerobic capacity: 1) maximal cardiac output, 2) maximal heart rate, 3) oxygen carrying capacity of the blood, 4) skeletal muscle characteristics and 5) pulmonary diffusing capacity. (Proctor and Joyner 1997, Shephard 1999, Bassett and Howley 2000, Basu et al. 2002.) Ageing affects all these factors in different ways. (Figure 3, the factors in bold face are considered in the present study)

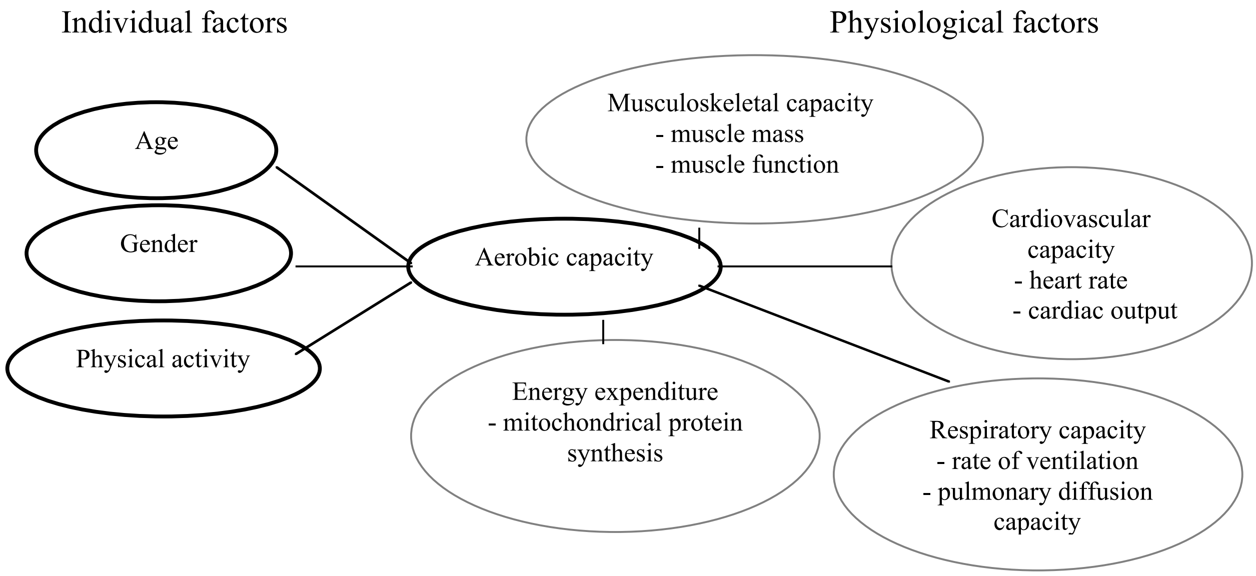

Figure 3. Factors in relation to aerobic capacity when ageing

Ageing diminishes aerobic capacity (VO_{2max}) between 0.25 to 0.9 ml · min^{-1} · kg^{-1} · $year^{-1}$ (0.5–1.5% annually) depending on age, gender and physical activity level (Rogers et al. 1990, Trappe et al. 1996, Pollock et al. 1997, Kasch et al. 1999). In addition, estimated decreases in muscle function for 10-year increases in age are substantial and clinically relevant, varying from 6.6% for VO_{2max} adjusted for lean tissue and activity-related energy expenditure to 42.6% for citrate synthase activity adjusted for activity-related energy expenditure (Hunter et al. 2002). Furthermore, a decline in mitochondrical protein synthesis rate could potentially play a role in the loss of aerobic capacity with ageing (Basu et al. 2002).

2.2.3.1 Age and gender

Age has been reported to explain 37% of the variance in aerobic capacity across ages 55–86 years (Paterson et al. 1999). In both sexes, age was the strongest independent predictor of aerobic capacity, followed by BMI. Together these two variables explained approximately 40% of the variation in aerobic capacity (Talbot et al. 2000). Furthermore, nearly one-half of the age-associated decline in relative aerobic capacity (expressed per kilogram body weight) was due to age-associated changes in body composition, including increased body fat and loss of lean muscle mass (Proctor and Joyner 1997). Furthermore, in a cross-sectional study it was reported that age, fat free mass, and exercise training status accounted for 66% of the variation in aerobic capacity (Rosen et al. 1998).

Age differences in aerobic capacity ranged from 22 to 26% on either an absolute (l · min^{-1}) or relative (ml · min^{-1} · kg^{-1}) basis. Aerobic capacity per kilogram of fat free mass was 16–17% lower in the older (over 50 years) than among younger subjects (aged 31 years or under). When expressed per kilogram of lean muscle, older men and women had VO_{2max} values that were 13–14% lower. When appropriately adjusted for age and gender differences in muscle mass, whole body VO_{2max} was 0.5 l · min^{-1} less in the older subjects than in the younger subjects. (Proctor and Joyner 1997.) In general women showed a slower age-related rate of decline in aerobic capacity than men, whereas the relative reduction was almost the same for both sexes (Paterson et al. 1999, Talbot et al. 2000).

The most important age-related cardiovascular change is a decline in maximal heart rate (HR_{max}), from around 195 beats·min^{-1} at age 25 years to 160–170 beats·min^{-1} at age 65 years (Shephard 1999) and was independent of training status (Pollock et al. 1997). This means about 25–35 beats in heart rate reserve (Kasch et al. 1999). Maximal heart rate across 55–86 years is not well predicted by age, in that age explained only 20 and 24% of the variance in HR_{max} in male and female subjects respectively. Physical activity, fat mass, and disease processes may modulate the rate of decline independently of the ageing process. In contrast to middle age and a usual gain in fat mass, older age is associated with a significant loss of lean body mass, and variable and smaller changes in total mass. (Paterson et al. 1999.)

2.2.3.2 Physical activity

A non-linear change in aerobic capacity has been found which is affected by interaction of age (65–79 years), level of physical activity and cardiopulmonary function. (Pollock et al. 1997). Total leisure-time activities accounted for 12.9% of VO_2 variance for men and 10.6% for women. After controlling for age and body mass index, leisure-time activities independently accounted for 1.6% of the VO_2 variation in men and 1.8% in women. The shift from vigorous to lower-intensity activities with advancing age may partially explain the decrease in cardiorespiratory fitness reflected in VO_{2max}. (Talbot et al. 2000.)

Commonly, frequency of training is negatively correlated with age (Pimentel et al. 2003). In a cross-sectional study on subjects aged 18–95 years, total leisure-time activities were inversely related to age in both sexes, mediated primarily by less high-intensity activities in older subjects, with only minor differences in moderate- and low-intensity activities across age. Aerobic capacity correlated positively with leisure-time activities, the correlations were strongest for high-intensity leisure-time activities. (Talbot et al. 2000, Pimentel et al. 2003.)

Age-related changes in aerobic capacity differ between different physical activity groups. It has been concluded that aerobic capacity declined linearly across the age range in sedentary men but was maintained in the endurance-trained men until around 50 years of age (Pimentel et al. 2003). The accelerated decline in VO_{2max} after 50 years of age in the endurance-trained subjects was related to decline in training volume (Tanaka et al. 1997, Eskurza et al. 2002, Pimentel et al. 2003). Moreover, the aerobic capacity was inversely and strongly related to age in sedentary, active and endurance-trained populations and was highest in endurance-trained and lowest in sedentary populations at any age. Absolute rates of decline in aerobic capacity with age were not different in sedentary, active and endurance-trained men (approximately 0.40 ml · min^{-1} · kg^{-1} · $year^{-1}$). (Rosen et al. 1998, Wilson and Tanaka 2000.) On the other hand, it was noted that the rate of decline in aerobic capacity with age was greater in the endurance-trained than in sedentary women and men (Tanaka et al. 1997, Pimentel et al. 2003). The absolute rate of decline was 0.54–0.84 and 0.32–0.40 ml · min^{-1} · kg^{-1} · $year^{-1}$ in the endurance-trained and in sedentary subjects respectively. Similar differences between men's groups existed when VO_{2max} was expressed in litres per minute and when normalized per kilogram of fat free mass (Pimentel et al. 2003), whereas the relative rate of decline in VO_{2max} was similar in these groups with advancing age (0.9–1.5% per year) (Tanaka et al. 1997, Wilson and Tanaka 2000, Pimentel et al. 2003). However, the VO_{2max} was 0.96 $l \cdot min^{-1}$ higher in athletes than in sedentary men at all ages (Rosen et al. 1998).

In some studies the differences in rates of decline in aerobic capacity were not related to changes in body mass or maximal heart rate (Tanaka et al. 1997, Eskurza et al. 2002). Nevertheless in the study by Rosen et al. (1998) the age-associated loss of fat free mass explained 35% of decline in aerobic capacity. Body composition changes may be less influential after age 65–70 years than the cardiopulmonary factors associated with reduced training in the reduction of VO_{2max} in endurance-trained subjects (Pollock et al. 1997). In endurance-trained and sedentary subjects, age was the primary predictor of VO_{2max}, describing 65–69 and 55–57% of the variance respectively. For both groups, percent body fat was the secondary predictor of VO_{2max}, accounting for an additional 9–10% and 20–21% of the variation in the endurance-trained and sedentary men and women respectively. (Tanaka et al. 1997, Pimentel et al. 2003.)

The normal range of VO_{2max} values ($l \cdot min^{-1}$) observed in sedentary and trained men and women of the same age is due principally to variation in maximal stroke volume, given that considerably less variation exists in maximal heart rate and systemic oxygen extraction (Bassett and Howley 2000, Eskurza et al. 2002). Trained individuals have a much higher maximal cardiac output than untrained individuals (40 versus 25 $l \cdot min^{-1}$). This leads to a decreased transit time of the red blood cells in the pulmonary capillary. Consequently, there may not be enough time to saturate the blood with O_2 before it exits the pulmonary capillary. Longitudinal studies have shown that the training-induced increase in VO_{2max} results primarily from an increase in maximal cardiac output rather than a widening of the systemic artery-vein oxygen difference. (Bassett and Howley 2000.) Moreover, there may be more than one mechanism responsible for population-specific differences in the rate of decline in VO_{2max} with age (Eskurza et al. 2002).

In addition the reduced VO_{2max} seen in highly trained older men and women relative to their younger counterparts is partly due to a reduced aerobic capacity per kilogram of active muscle independent of age-associated changes in body composition, i.e. replacement of muscle tissue by fat. Skeletal muscle adaptations to endurance training can be well maintained in older subjects, the reduced aerobic capacity per kilogram of muscle likely results from age-associated reductions in maximal oxygen delivery (cardiac output and / or muscle blood flow). (Proctor and Joyner 1997.)

There was substantial variation in maximal heart rate among both young adult and older adult subjects, with the largest interindividual variability observed in endurance-trained subjects over 50 years of age (Tanaka et al. 1997). Maximal heart rate was inversely related to age. Rate of decline in maximal heart rate is not associated with habitual exercise status and gender. (Wilson and Tanaka 2000, Pimentel et al. 2003.)

2.2.4 Flexibility of the spine

The range of motion of healthy human joints is a function of various tissues, which surrounding the joint. These tissues include adipose tissue, the joint capsule muscles, tendons and ligaments. (Stubbs et al. 1993.) There is a general negative relationship between age and joint range of motion. The reduced range of motion in older people is due to the replacement of elastin with collagen, an increase in collagen, and a decrease in elasticity due to an increase in cross-linkage of collagen fibres within the soft tissue components of the spinal column (Taylor and Twomey 1980). In addition, various macrostructural and microstructural changes have been identified. These changes result in an increased rigidity and may be the result of biochemical alterations at the molecular level in the collagen protein fibres. These changes are both physical (a reorganization of fibres during healing due to micro and macro traumas through life) and physiological (the formation of intermolecular and intramolecular cross links and the uptake of minerals) leading to increased elastic stiffness and shrinkage. (Stubbs et al. 1993.)

The semiquantitative analyses of age-related changes of lumbar intervertebral discs have been provided clear histological evidence for the detrimental effect of a diminished blood supply on the endplate, resulting in tissue breakdown beginning in the nucleus pulposus in the second life decade. Significant temporospatial variations in the presence and abundance of histological disc alterations were observed across levels, regions, macroscopic degeneration grades and age groups. They concluded that diminished blood supply to the intervertebral disc in the first half of the second life decade appears to initiate tissue breakdown. (Boos et al. 2002.) Underlying joint changes occurring as part of ageing may or may not be associated with overt pathology in the cartilage and bone compatible with osteoarthritis, such as degeneration of the cartilage and sclerosis of the subchondral bone (Hamerman 1998). Soft tissue changes may also play a role as limiting factors in spinal and thoracic movements, being, however for the most part difficult to detect by common visualisation techniques. Spinal mobility is reduced long before radiological alterations are evident. (Viitanen et al. 2000.)

Many studies have shown that age appears to have an influence on the flexibility of the spine (e.g. Alaranta et al. 1994b, McGregor et al. 1995, Hasten et al. 1996). It has been reported that the degree of disc degeneration varied among individuals and between different discs. Over the age of 60, most of the discs were markedly degenerated. The L4-5 and L5-S1 discs were more significantly degenerated than the L3-4 discs, L4-5 facet joints were more degenerated than any other level, and no difference between genders was noted. (Fujiwara et al. 1999.)

A gradual loss of flexibility of the lumbar spine has been noted with each decade, with the annual decline averaging about 1.0% between 50 and 70 years of age (McGregor et al. 1995). In the cross-sectional study on age groups 25–34, 35–44 and 45–54 years, it was noted that the decrease was 0.2–1.5% year^{-1} in lumbar / thoracic forward flexion. In addition, there were some differences between right and left side range of motion (especially in the wrist and glenohumeral joints). The differences in joints between dominant versus non-dominant side may be a consequence of several factors 1) a muscle might be hypertrophied on the dominant side thus giving the non-dominant side a larger range of motion 2) increased muscle tonus on the dominant side could also explain the greater amplitude of motion and 3) microtrauma. (Stubbs et al. 1993.)

It has been observed that women had better cervical flexion-extension-movement and side bending but lower rotation movements than men. Instead, men had greater ranges of motion in lumbar flexion than women. There was a clear inverse relationship between age and cervical flexibility and this was also noted after adjustment for sex and occupation. In addition, lumbar flexion showed about 0.5% annual decrease with age between the youngest (35–39 years old) and the oldest (50–54 years old) subjects. (Alaranta et al. 1994b, Troke et al. 2001.) On the other hand, Ensink et al. (1996) did not suggest any significant correlations between lumbar range of motion and gender and age of the subjects.

There are differences in changes of flexibility of the spine depending on which movement is examined. The greatest decrease in spinal mobility has been observed in trunk side bending, about 1.0% per year, between 35 to 54 years of age (Alaranta et al. 1994b). On the other hand, it has also suggested that the greatest decline was in spine extension by approximately 1.0% per year. Moreover, in side bending male and female ranges declined in each direction about 0.6% per year. Instead, in axial rotation no age-related decline was observed. (Troke et al. 2001.)

2.3 Physical capacity and work

2.3.1 Different workloads

In general the individual's capacity for strenuous work remains important with respect to successful work performance (Karlqvist et al. 2003a). Most occupational activities are performed through human intervention. In such cases, a person's capacity to perform mechanical work is determined by his/her ability to exert muscular strength. The demands for human strengths to accomplish physical activities remain strong despite increasing automation. The nature of many tasks and work situations requires the recruitment of muscle power. A number of personal and task factors influence human strength. The factors that are particularly important are age, gender, posture, reach distance, arm and wrist orientations, speed of exertion and duration and frequency of exertions. (Anil and Shrawan 1998.)

In general, in healthy individuals, the aged pulmonary system functions well, and has not usually been found to be the limiting factor in exercise performance. In exercise using small muscle groups, where muscle factors set the limits for physical work capacity, age is not necessarily the main limiting factor. In physical work tasks requiring the dynamic use of large muscle groups, the older people would seem to be at a greater disadvantage relative to young people. (Aminoff et al. 1996.)

Work, but not age, has a significant effect on the muscle strength if the results from all the muscle groups are evaluated as a whole (Schibye et al. 2001). Physically heavy work seems to have a different impact on different components of physical capacity and the effect differs between genders. Women who had the highest work demands had significantly lower muscle endurance in the abdomen and legs, poorer aerobic capacity (Torgén et al. 1999a) and poorer coordination than women with the lowest job demands (Karlqvist et al. 2003b). However, it has been proposed that high physical demands on a job had a training effect on the upper extremities, especially among men (Torgén et al. 1999a). On the other hand, it has also been found that the maximal isometric hand-grip strength of women (over 50 years) with a load classified as sustained of static or dynamic load on the hands at work was 86 and 88%, respectively of the strength of those with a load of short duration. There were no differences in isometric trunk muscle strength or dynamic trunk flexor strength between high and low workload groups, although the high workload group had systematically the lowest muscle strength and muscle endurance in almost all comparisons. However, muscle strength and muscle endurance did not discriminate between the group classifications of static and dynamic work. (Nygård et al. 1988.)

The study by Schibye et al. (2001) on aerobic capacity and muscle strength among male workers with and without physically demanding work tasks also showed that the physical work seems to have a training effect, especially for the shoulder muscles. Besides, no training effect was found in aerobic capacity. (Schibye et al. 2001.) However, it has been reported that the perceived physical job strain had a significant positive correlation with relative aerobic capacity (Sörensen et al. 2000). Furthermore, Nygård et al. (1991, 1994) perceived that physical work had no training effects on physical capacity during ageing and occupational physical activity over many years may even cause capacity to deteriorate. It has been proposed that age explained significantly the variation in aerobic capacity. Among females age explained 19% and among males 30%. Age is the most important determinant for capacity and occupational physical activity adds only little to this. (Nygård et al. 1994.)

Physical activity is also related to the differences in muskuloskeletal capacity between different work categories. Rantanen et al. (1993) studied the association between a history of heavy work and muscle strength among physically active women aged 66–85 years and physically passive women aged 70–81 years. They measured maximal isometric muscle strength of hand-grip, arm flexion, leg extension and trunk flexion and extension and endurance of trunk flexors. Among the trained women there was no correlation between the amount of heavy work and muscle performance. Instead, among the untrained women the amount of heavy work correlated positively with maximal isometric trunk extension strength. Rantanen et al. (1993) suggested that among elderly women, whether physically active or not, a history of heavy work has no systematic association with muscle strength. Maximal isometric handgrip, knee extension and trunk flexion and extension forces were significantly greater among the trained women, who also had greater trunk flexor endurance than the untrained women. The association between occupation and muscle strength seems to vary in different age groups among women. (Rantanen et al. 1993.)

It has been established that the flexibility of the spine decreased with advancing age, particularly among blue-collar workers. Instead, no significant difference was observed between white-collar and blue-collar occupations with respect to lumbar flexion. In lumbar extension the blue-collar workers showed a greater range of motion than white-collar workers. Trunk rotation and trunk side-bending showed differences between occupational groups, blue-collar workers having a lower range of motion. (Alaranta et al. 1994b.)

2.3.2 Factors affecting workload

Age

Above all, a major problem in physical exposure assessment concerns the variability in exposure between workers performing the same job. Some individual stays healthy even after long-term exposure. The reasons for this discrepancy may either be differences in susceptibility or differences in individual exposure. (Balogh et al. 1999.) Bunce and Sisa (2002) investigated the age differences in perceived workload across short vigilance tasks. They showed that while older participants were able to maintain the same performance level as their younger colleagues, they perceived a greater increase in the workload associated with that demand for vigilance. By compensating their performance in this way, it was likely that older adults were placing greater demands on attentional resources. Perceived mental, physical and temporal demands increased across the task more among the older individuals than the young participants. (Bunce and Sisa 2002.) On the other hand, it has been found that the rating of perceived exertion (RPE) did not differ between 23–30-year old and 54–59-year-old men in dynamic exercise (Aminoff et al. 1996). Moreover, the results of Louhevaara (1999), on blue-collar men workers suggested that the overall and local RPE revealed no difference in perceived workload due to age. Louhevaara (1999) moreover found that energy expenditure, heart rate and the proportion of poor work postures were similar when the ageing and young subjects were compared in their occupational groups.

Nordander et al. (2000) studied the work exposure of female hospital cleaners, and of female and male office workers. They found that the inter-individual variation in exposure was explained by body mass index and age. In addition there was a large inter-individual variation in muscle activity within each occupational group, even when the same task was performed. For the cleaners, some of the variation was explained by body mass index and age, with lower values of muscular rest for older subjects with a high BMI. Among the office workers no effect of age was found. No significant difference was shown for any workload (EMG) measure between genders among office workers. However, men had lower values for peak load than women. Gender, strength, smoking, job strain, duration of employment and musculoskeletal symptoms had no impact. (Nordander et al. 2000.) Furthermore, it has been concluded that individual work technique and anthropometrics are stronger determinants of exposure than task characteristics or exposure group membership (Fallentin et al. 2001).

Gender

According to an interdisciplinary study women who exceeded their aerobic capacity at work had typically low skill discretion, more often atypical work hours and more time-bound work than women with low work demands, while the men with high demands at work showed high circulatory strain during leisure-time activities. In addition, it was noted that many risk factors accumulate in individuals who were required to exceed their individual aerobic capacity at work. These factors were different between genders. In women poor health was observed, with anything from poor general health to musculoskeletal disorders to impaired mental health. Instead, among men no such health disorders were seen. Moreover, women who exceeded their aerobic capacity at work were significantly heavier than the women with low work demands. (Karlqvist et al. 2003b.)

In general physical workloads were higher among men than among women at younger ages (below 30 years), but the difference was less pronounced at higher ages. However, it has been suggested that the perceived exertion was equal among the men and women, with only minor changes over 20 years. (Torgèn and Kilbom 2000.) It has also been proposed that women perceived higher physical demands than men (Nygård et al. 1997, Hansson et al. 2001). A correlation between RPE and relative heart rate range (%HRR) was observed among men, whereas no correlation was observed for women. The difference in the validity of the self-reports may be attributable to occupational differences and not gender differences per se. (Hjelm et al. 1995.)

On the other hand, it has been noted that men tended to work at a higher absolute workload, but a lower relative load than women when they were doing the same kitchen work. In the study by Aminoff et al. (1999) was noted that the male subjects tended to rate lower values than the females. In addition individuals with a higher VO_{2max} and task-specific VO_{2peak} performed the same work with a higher VO_2 than those with lower maximal and peak values. The relative load was similar among the subjects, independent of fitness. This could be explained by a more dynamic way of working among individuals with greater fitness. They helped other workers at the belt by emptying and sorting dishes, which was not part of their work task. Therefore, those persons with a better fitness level were more productive than those with a lower fitness level. (Aminoff et al. 1999.) Sandmark et al. (1999) measured and quantified exposure to physical workload in physical education teachers. The ratings of perceived exertion (Borg scale) of the day as a whole gave values for women from “very light'' to “strenuous'' and for men the exertion was rated from “very, very light'' to “somewhat hard” (Sandmark et al. 1999). It should also be emphasised that factors such as mental stress and heart rate peaks could contribute to perceived physical strain (Theorell et al. 1991).

3 Aims of the study

The main purpose of this study was to ascertain changes in musculoskeletal and cardiovascular capacity in relation to different workloads during the long follow-up period.

The more specific aims of this study were to ascertain

1) how musculoskeletal and cardiovascular capacity change with age
2) if there are differences in physical capacity in relation to different workloads
3) if physical capacity among employees with different workloads is associated to the assessment method of workload (i.e. subjectively and/or objectively assessed).

4 Subjects and methods

4.1 Subjects and methods of the study on municipal employees (Studies I, III and IV)

4.1.1 Study design

This follow-up study is one part of a larger project concerning Finnish municipal workers during the period 1981–1997. The aim of the entire project was to determine changes in the work, lifestyle, health, functional capacity, work ability and work stress among ageing municipal employees. The project included questionnaires (health, work ability, lifestyle and work environment), field measurements (workload and strain) and laboratory measurements (physical capacity). (Ilmarinen et al. 1991c). The questionnaires and laboratory measurements were conducted four times during the follow-up period: in 1981, 1985, 1992 and in 1997. The assessments of workload were done at the beginning of the follow up period in 1981. In this follow-up study, the data consisted of results from physical capacity tests, objectively and subjectively assessed workload and from questionnaires.

All the subjects who participated in both the laboratory and field measurements completed the questionnaire in the same year. In this study, the questionnaire data were only used for background information about the subjects' chronic diseases (musculoskeletal, cardiovascular and respiratory diseases), physical activity (scale 1–5, active–passive) and type of pension (e.g. old-age, disability pension). Study design and the number of subjects who took part in laboratory and field measurements in different years are presented in Figure 4.

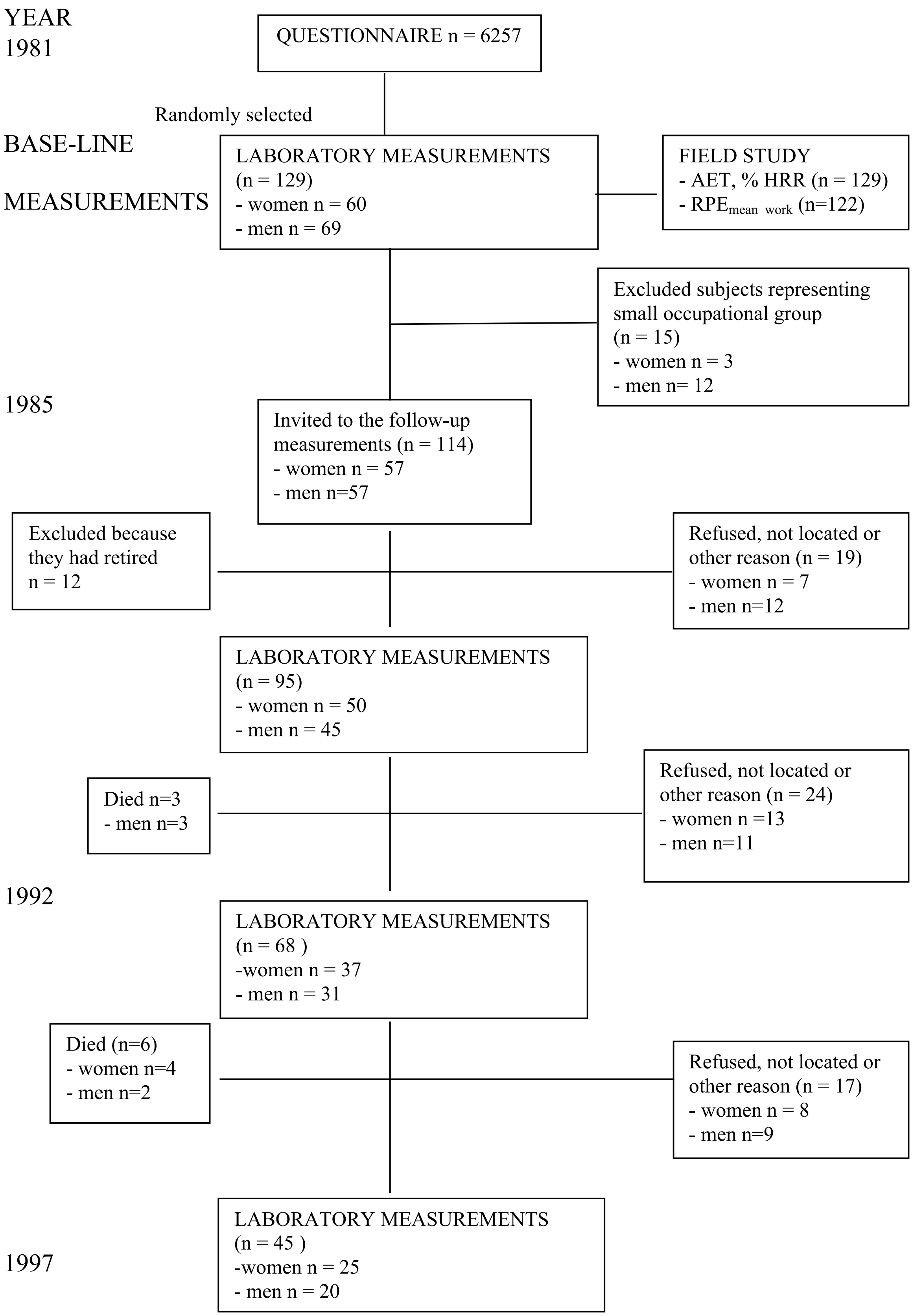

Figure 4. Study design of the study on municipal employees

4.1.2 Study subjects

The subjects for the laboratory measurements were randomly selected from among those who responded to a questionnaire in 1981 concerning work ability, health, and work environment (N=6257). The sample represented workers employed in municipal occupations in different regions of Finland. In the field measurements and in the first laboratory measurements conducted in 1981, there were 129 subjects, with a mean age among women of 51.6 (range 46–58) years and among men of 51.4 (range 47–56) years (Ilmarinen et al. 1991c). In the most recent laboratory measurements (1997) the mean age of participating subjects was 67.3 years among both women and men (range 62–74 years in women and 61–72 years in men). (Figure 4)

In 1981, all subjects were employed and they had been in the same occupation on average for 20.2 years (range 4.0–41.0 years). There were 95 of the subjects who had follow-up information. In 1997 two of the 95 subjects had changed occupation, 48 were on old age pension, 33 were on disability pension, nine had died and for three persons we had no information.

In Study I out of the original sample of 129 subjects in 1981 a total of 45 subjects (25 women and 20 men) were also examined in 1985, 1992.

In the second laboratory measurements of 1985, the number of participating subjects was 95. These subjects were included in Study III.

The number of subjects who participated in the second laboratory measurement and had also subjectively assessed workload (perceived workload) was 89. These were included in Study IV. In 1997, 75 of the 89 subjects had retired, nine had died, on three subjects no information was available and only two of the 89 subjects were still working. (Study IV)

4.1.3 Methods

4.1.3.1 Laboratory measurements (Studies I, III, IV)

At every measurement height and weight were measured and body mass index (BMI, $kg \cdot m^{-2}$) was calculated (Keys et al. 1972). In addition in Study I the skin fold thickness (triceps and subscapular) was measured from the right side with a skin fold caliper (John Bull®, British Indicators Ltd., England) (Nygård et al. 1987a). (Study I)

By measuring flexibility of the spine, maximal handgrip strength, maximal trunk extension and trunk flexion strength musculoskeletal capacity was assessed. The flexibility of the spine was assessed in a standing position. The increase in the length of spine between the seventh vertebra cervicalis and the first vertebra sacralis was measured with the back bent forward and the knees kept straight. (American Academy of Orthopaedic Surgeons 1965.) The maximal isometric handgrip strength of the dominant hand was measured with a manometer (Martin Vigorimeter®, Germany). The device consisted of a rubber ball connected to a mechanical transducer with readout. Two sizes of rubber ball were used, a smaller one for women and a larger one for men. The subjects performed two maximal handgrip exertions of which the higher value was recorded. (Nygård et al. 1987a.) The maximal voluntary isometric muscle strength of the trunk flexors and trunk extensors was measured with a calibrated dynamometer (Asmussen et al. 1959, Nygård et al. 1987a).

Aerobic capacity (VO_2max) was assessed by a submaximal bicycle ergometer test (Ilmarinen et al. 1991a). The tests were carried out on a calibrated, mechanically braked cycle ergometer (Monark A/S, Sweden). The bicycle test was preceded by a medical examination where a physician ascertained the suitability of each individual to take part in the test and all medications were recorded. Before, during, and after the test an electrocardiogram was recorded (Minograf 34, Siemens-Elema, Germany).

Twelve women and six men showed contraindications for the test, either heart dysfunction or medication affecting the heart rate, leaving a total of 13 women and 14 men who participated in all four ergometer tests (i.e., 1981, 1985, 1992, and 1997). (Study I)

There were 55 employees who could participate in the aerobic capacity test in 1981 and 31 subjects in 1997 (Study III).

In Studies III and IV the different physical capacity variables were categorised separately for women and men for two groups: poor and good physical capacity. The good physical capacity group consisted of subjects whose results were over median for gender and variable. The rest of the study subjects composed the poor physical capacity group. In the group level analysis, the men and women were analysed together.

4.1.3.2 Field measurements

Assessment of musculoskeletal load (Study III)

A job analysis and measurements of individual work strain were carried out in 1981 among 129 subjects (Suurnäkki et al. 1991). The subjects were chosen from different Finnish municipalities. The field studies were done in technical professions (39%), health care (22%), social welfare (13%), administrative and office work (10%) and in miscellaneous work e.g. painters, cleaners (16%). (Ilmarinen et al. 1991b.)

The characteristics and demands of the different occupations were analysed at the beginning of the study with the ergonomic job analysis procedure commonly known as the AET method (Arbeitswissenschaftliche Erhebungsverfahren zur Tätigkeitsanalyse) (Rohmert and Landau 1983). The method incorporated observations of the work and interviews with the workers and supervisor. In all, 216 different items associated with the work system, work tasks and work demands were rated (Ilmarinen et al. 1991b). Seventeen of the 216 items concerned physical demands at work and from these items a musculoskeletal index was formulated (Nygård et al. 1987b). The musculoskeletal index could theoretically range from 0 to 70.7, but in the present study it ranged from 4.0 to 27.8. (Table 2) Calculating Cronbach's alpha coefficient validated the internal consistency of the musculoskeletal index (α = .70). The musculoskeletal index was categorized in two groups: physically high and low workload separately for women and men based on the medians of the original sample (n=129). In the present study the physically high workload group consisted of the subjects scoring above the median of the index among the study subjects (n=47; women n=23 and men n=24). The physically low workload group consisted of those subjects scoring median or under on the index among study subjects (n=48; women n=27 and men n=21). The cut points of categories were 14.3 for women and 17.3 for men.

Assessment of cardiovascular strain (Study III)

The heart rate (HR, beats · min^{-1}) during the work shift was registered minute by minute with a portable heart rate meter with a microprocessor (Saris et al. 1977) or with a Howel Corder tape recorder (Rutenfranz et al. 1977). The mean heart rate at work was related individually to the heart rate range (%HRR), the estimated maximal heart rate [210–(0.8 x age)] and the lowest measured heart rate during work shift being used for the calculations (Ilmarinen 1978). The relative heart rate range (%HRR) varied from 8.0% to 67.0% (Table 2). The strain on the cardiovascular system was categorized in the present study for two groups using the cut point based on Ilmarinen (1992): physically low strain < 30% (n=75; women n= 41 and men n=34) and physically high strain ≥ 30% (n=20; women n=9 and men n=11).

Assessment of perceived workload (Study IV)

Perceived workload was assessed by the ratings of perceived exertion (RPE, scale 6–20) at work developed by Borg (1970). A researcher asked the subjects to rate their perceived workload after 1, 3, 5, and 7 hours from the beginning of the work shift during one working day. The mean of three or more of these ratings ($RPE_{mean\ work}$) was used for the analysis. The total number of subjects was 122 for whom the $RPE_{mean\ work}$ could be calculated; seven of the 129 subjects had fewer than three ratings because they had a shorter working day. (Figure 4) The perceived workload was categorised separately for women and men in two groups: high and low workload. The high workload group consisted of subjects whose RPE_{mean} was over median regarding gender n=59 (women n=28 and men n=31). The subjects scoring median or under formed the low workload group n=63 (women n=30 and men n=33). The cut-off points of categories were 12.5 among women and 12.8 among men. In the group level analysis the men and women were taken together.

4.1.3.3 Questionnaire

All the subjects who participated in both the laboratory and field measurements completed the questionnaire of the same year. In Studies III and IV the questionnaires data are only used for background information on the subjects such as chronic diseases, physical activity and type of pension.

In Study I, categorizing variables used included chronic diseases and physical activity level. Diseases diagnosed by a physician were assessed using questionnaires. In Study I only diagnosed musculoskeletal, cardiovascular, and respiratory diseases were considered because of their assumed impact on physical capacity. The frequency of diseases was categorized as one, two or three diseases.

At each administration of the questionnaire (1981, 1985, 1992 and 1997) the physical activity of the subjects was determined by asking each participant the following question: "How often on average did you exercise during the whole year in 1981 (or 1985, 1992, and 1997)?" Exercise was defined as physical activity having duration of at least 15–20 minutes, while also taking account of the extent of breathlessness during the exercise or physically demanding leisure time activity. Brisk exercise was determined as physical activity inducing breathlessness. Respondents were categorized into one of five physical activity levels: 1. brisk exercise at least twice a week, 2. brisk exercise at least once a week, 3. some exercise once a week, 4. some exercise less than once a week and 5. no exercise.

To assess the individual's self-reported physical activity level the answers to all four questionnaires (1981–1997) were used. Subjects were divided into two groups: (a) active, those reporting brisk exercise at least once a week for a 15–20 min period (levels 1–2), and (b) passive, those reporting some exercise once a week or less (levels 3–5). (Study I)

4.1.3.3 Data analysis (Studies I, III and IV)

The calculations of the total changes in physical capacity (%) during the study period were based on the means from an individual's change in a certain variable (i.e., change scores were calculated by taking the last measurement value minus the first measurement value divided by the first and then multiplied by 100). In trunk flexion, trunk extension and aerobic capacity the number of subjects varied because only the first and the last measurements were taken instead of all four. The changes were calculated separately for men and women.

In Study I, to evaluate if the changes in physical capacity variables were statistically significant, the repeated measures analysis of variance with year (1981, 1985, 1992 and 1997) used as the repeated measure was performed. Gender was used as a between subject factor.

The differences in total changes between gender, physical activity and long-term disease groups were compared using independent sample t test or one-way analysis of variance (ANOVA). As isometric trunk extension and aerobic capacity variables were not normally distributed, a logarithm transformation was carried out. (Study I)

In Studies III and IV the calculations of incidence density of poor physical capacity were based on the cases where the category of physical capacity variable declined from good to poor over two measurement years (between 1981–85, 1985–92 and 1992–1997).

$$\text{Incidence density of poor physical capacity} = \frac{\sum \text{cases whose physical capacity declined between 1981–85, 1985–92 and 1992–97}}{\sum \text{(person years of cases + person years of non-cases)}}$$

Likewise the calculations of incidence density of good physical capacity were based on cases where the category of physical capacity variable improved from poor to good over two measurement years.

$$\text{Incidence density of good physical capacity} = \frac{\sum \text{cases whose physical capacity improved between 1981–85, 1985–92 and 1992–97}}{\sum \text{(person years of cases + person years of non-cases)}}$$

person years (pyrs) = a measurement combining persons and time as the denominator in incidence rates when individual subjects are at risk of declining / improving physical capacity. It is a sum of the periods of time at risk for each of the subjects. Each subject contributes only as many years of follow-up to the population at risk as the period over which that subject has been followed.

The incidence density of poor and that of good physical capacity per 1000 person years (10^3 pyrs) was calculated differently for the low and high workload groups.

The differences in physical capacity variables between workload groups and the difference between the subjects whose workload group differed depended on the assessment method of workload and the subjects whose workload group was the same independent of the assessment method of workload were analysed for statistical significance, using the Mann-Whitney test. The reference group in comparing the differences between differently assessed workload groups was the group which was the same independent on the assessment method. It was assumed that among them the physical capacity was not the factor, which affects the workload category. (Studies I, III, IV) The statistical analyses were performed using SPSS 11.0 programme. All tests were considered statistically significant if $p < .05$.

4.2 Subjects and methods of the study on women in physically demanding work (Study II)

4.2.1 Study design

The subjects of this investigation were ageing women working in the same food factory in 1989 (N=127). The inclusion criteria for the study subjects were that the women had responded to questionnaires and taken part in physical capacity tests both in 1989 and 2000 and that they perceived their work as either physically or mixed mentally and physically demanding (n=60). (Figure 5) The subjects were included in the study after they had been fully informed about all of its parts and had given their informed consent to participate. The study was reviewed and approved by the Ethic Committee of Tampere University Hospital, Tampere, Finland.

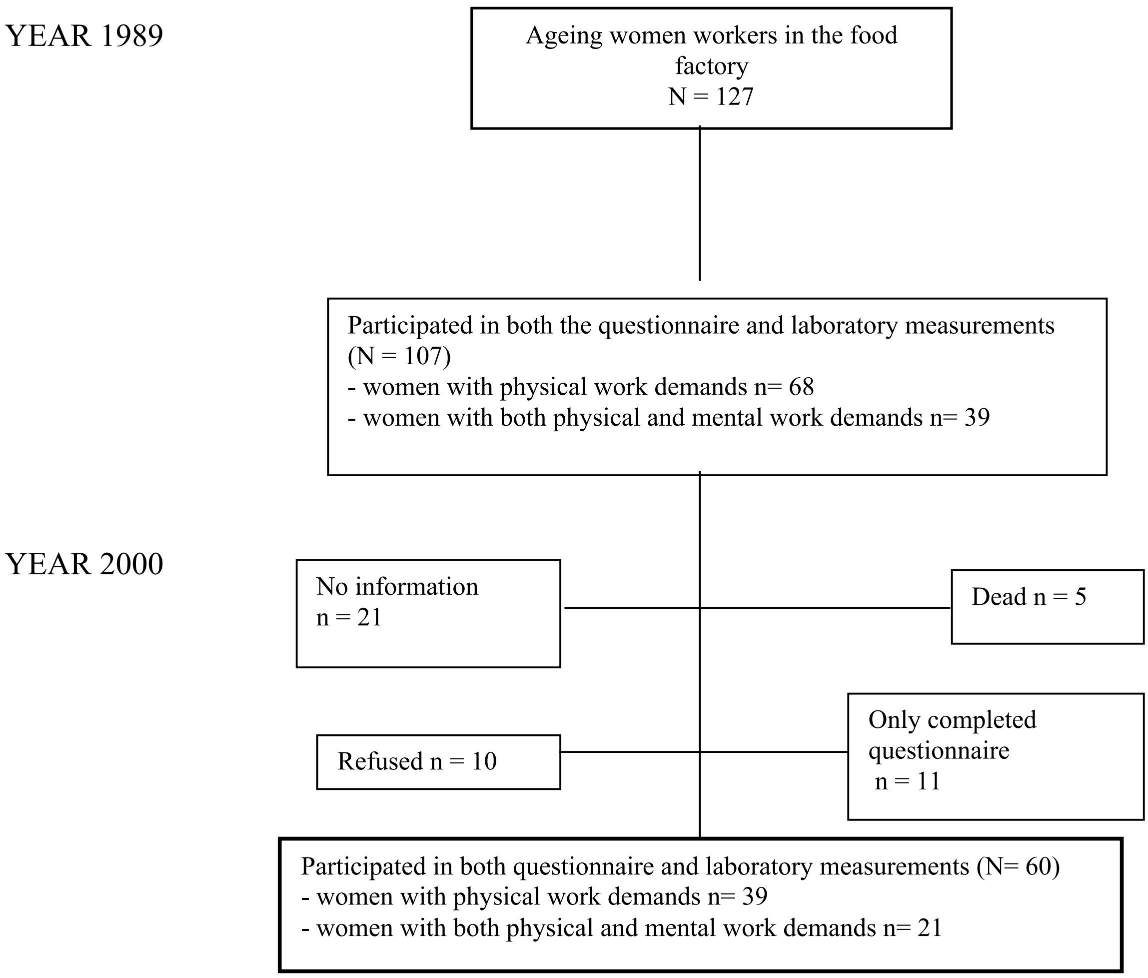

Figure 5. Study design of the study on women in physically demanding work

4.2.2 Study subjects

The mean age of the women was 52.3 years (range 44–62) in 1989 and 62.9 years (range 55–72) in 2000. At the end of the follow-up, their mean working history was 20.0 years (SD 9.5, range 2.0–48.0 years) at the same work in this food factory. During the follow-up one subject changed workplace but her work remained physically demanding. All the subjects perceived their work demands of the year 2000 to be the same as in the year 1989. The perceived work demands of the year 2000 correlated very significantly with the work demands of the year 1989 (contingency coefficient was 0.707, $p < .001$).

There were no differences between different work demand groups in age and in the length of working history. In 2000, sixteen of the 60 women were still in working life, 15 were on old-age pension, 15 were on disability pension and 14 were unemployed or on unemployment pension. The mean time of being retired or out of working life was 4.2 years (SD 2.9, range 0–9.0 years). There were no differences in the working status and in the mean time of being retired between different work demand groups. The subjects left working life straight from the food factory.

4.2.3 Methods

4.2.3.1 Laboratory measurements

Height and weight were measured and body mass index (BMI) was calculated (Keys et al. 1972) for all 60 women. Muscle strength was tested using the repetitive sit-up, arch-up, squatting and static back endurance tests (Alaranta et al. 1994a). In addition the static and dynamic strength of the upper limbs were tested. In the static test, the subject was standing, feet 15 cm apart and held a 5 kg weight with both arms outstretched in front of her at right angles for as long as possible, the maximum time was 90 seconds. In the dynamic test the initial position was the same as in the static test. In the dynamic test the subject lifted 5 kg weights alternately straight up as many times as possible, the maximum result for both arms was 50 times. As a result, the mean of repetitions was calculated. Forty-five women (physical work n=30 and mixed work n=15) participated in the muscle performance test in both years. Fifteen out of the 60 women had some contraindication for the performance tests e.g. acute low back pain or tendinitis in the shoulder either in 1989 or in 2000.

Aerobic capacity (VO_2max) was assessed by a submaximal bicycle ergometer test (Louhevaara et al. 1980). The tests were carried out on electrically braked bicycles (Tunturi E850 Pro Ergometer®, Finland and Siemens EM 847®, Germany). The bicycle test was preceded by a medical examination where a physician ascertained the adequacy of the health of each individual to participate in the test and all medications were recorded. There were 14 women (physical work n=12 and mixed work n=2) who were able to participate in the test in both years and had no contraindications either in 1989 or in 2000. Heart dysfunction and medication affecting heart rate were contraindications for the test. Heart rate was monitored (Polar Pacer®, Finland) during warm-up, the test and cooling off.

The performance tests of physical capacity were the same in 1989 and 2000. The tests were done in an occupational health care facility by an occupational health physiotherapist. In 2000, for the women who were no longer working at the food factory, the occupational health physician and physiotherapist did the tests at a university research unit.

4.2.3.2 Questionnaire

The work demand group was based on the perceived work demands of the subjects elicited in the questionnaire of 2000. The subjects were asked "Is your current work mainly (a) mentally, (b) physically, or (c) both mentally and physically demanding?" If the subject was not working in 2000, the question was "Was your last work mainly (a) mentally, (b) physically, or (c) both mentally and physically demanding?"

Physical activity level and diseases diagnosed by a physician were used as background variables. Physical activity level was categorized for two groups: the active group consisted of women who took brisk exercise at least once a week for 15 to 20 minutes, and the passive group consisted of women who took some exercise less than once a week or no exercise at all. Brisk exercise was defined as physical activity inducing breathlessness. Illnesses were also categorized into two groups: one was no diagnosed disease and the other at least one diagnosed disease.

4.2.3.3 Data analysis

The data were analysed for statistical significance using the paired t-test and independent t-test for normally distributed variables and Wilcoxon and Mann Whitney tests for variables which were not normally distributed (BMI in 1989, height and dynamic trunk flexion in 1989 and 2000) when comparing the differences in physical capacity between work demand groups in 1989 and in 2000. The differences in the changes of aerobic capacity between the two different work demand groups were not analysed, because aerobic capacity both in 1989 and 2000 was available for only 14 women.

The calculations of the total relative changes (%) in physical capacity during the study period were based on medians from an individual's change in a certain variable (i.e. change scores were calculated by taking the last measurement value minus the first measurement value divided by the first and then multiplied by 100). Most of the total change variables were not normally distributed so medians were used in the results of total changes and the Mann-Whitney test to assess statistical differences between groups. For the differences between categorized variables (physical activity level and diseases) chi-square test was used. The statistical analyses were performed using SPSS 9.0 programme. All tests were considered statistically significant if $p<.05$. (Study II)

5 Results

In general the percentage of subjects having some chronic disease and the number of chronic diseases increased during the follow-up period. At the beginning of the follow-up on average 70% of the subjects had some diagnosed chronic disease compared to 90% of subjects at the end of the follow-up. There were no differences between workload groups in the proportion of the subjects who had some chronic disease at the end of follow-up.

In addition the proportion of physically active subjects increased (i.e. categories labelled brisk exercise at least once a week or more for 15–20 min, with perceived breathlessness). The proportion of physically active subjects increased over 25% (from 27–42 to 58–67%) during follow-up. There was no statistically significant difference in physical activity between genders or between different workload groups. On average, people without disease or who were physically active displayed better physical capacity than people with disease or who were physically passive. (Studies I–IV)

Overall, the changes in different components of physical capacity were statistically significant among women and men. Among both women and men the only exception was thickness of skin folds. (Table 1) In addition, among women the changes in dynamic trunk muscle and static upper limb strength were not significant. (Study II)

The changes in muscle strength were different between genders. In general the muscle strength decreased more among men than among women. Women's handgrip strength was 80.6–100% of men's handgrip strength depending on the measurement time. At the end of follow-up, the mean value in handgrip strength was almost equal in women and men. Men had better in trunk muscle strength than women at every measurement. Women's isometric trunk flexion strength remained at 63.7–81.4% of men's flexion strength, whereas women's isometric trunk extensor strength was 65.1–74.8% of men's extensor strength depending, however, on the time of measurement.

Regarding the flexibility of spine and aerobic capacity there were no differences in changes between genders. The decrease in aerobic capacity was equal among women and men. Changes in aerobic capacity among women were 0.25 ml $\cdot$ min^{-1} $\cdot$ kg^{-1} $\cdot$ year^{-1} and among men 0.28 ml $\cdot$ ml^{-1} $\cdot$ kg^{-1} $\cdot$ year^{-1}. Means and standard deviation of anthropometrics and physical capacity variables by gender 1981–1997, and changes over time (T), differences between gender (G) and time by gender interaction (TxG) are seen in Table 1.

Table 1 Means and standard deviations of anthropometrics and physical capacity variables by gender 1981-1997, and changes over time (T), differences between gender (G) and time by gender interaction (TxG) using analysis of variance for repeated measures (p-values)

Variable	Measurement point								p-value		
	1981		1985		1991		1997				
Gender	M	SD	M	SD	M	SD	M	SD	T	G	TxG
Weight (kg)											
Women (n=25)	66.8	8.2	68.3	9.0	68.8	10.0	71.0	9.6	<.001	<.001	ns
Men (n=20)	78.3	10.1	78.8	10.3	82.9	12.1	82.0	11.8			
Height (m)											
Women (n=25)	1.60	5.1	1.59	5.1	1.60	5.1	1.59	5.3	<.001	<.001	ns
Men (n=20)	1.75	6.8	1.74	6.7	1.74	6.9	1.73	6.5			
Body mass index ($kg \cdot m^{-2}$)											
Women (n=25)	26.2	3.3	27.0	3.3	27.0	3.8	28.3	3.9	<.001	ns	ns
Men (n=20)	25.7	3.2	26.1	3.2	27.3	3.8	27.2	3.6			
Thickness of skinfolds (mm)[a]											
Women (n=25)	48.2	16.2	45.2	15.4	45.3	14.2	46.8	12.2	ns	<.001	ns
Men (n=20)	29.9	8.0	27.4	5.5	32.3	10.5	31.1	8.4			
Flexibility of spine (mm)[b]											
Women (n=24)	74.8	15.0	79.4	14.9	62.8	14.7	53.0	2.8	<.001	ns	ns
Men (n=20)	71.5	13.2	77.6	14.4	61.7	15.2	57.3	3.0			
Hand grip strength (kPa)											
Women (n=25)	81.8	15.5	81.4	20.0	81.5	17.6	77.2	16.9	<.001	.04	.001
Men (n=20)	101.4	22.2	94.3	18.7	86.9	17.6	77.5	15.2			
Trunk flexion (N)											
Women (n=16)	432.1	132.1	350.0	116.2	263.6	111.8	359.3	111.8	<.001	<.001	.002
Men (n=15)	678.7	169.2	500.5	117.1	390.4	116.1	441.5	131.1			
Trunk extension (N)											
Women (n=16)	473.8	141.8	402.6	157.7	355.0	138.2	368.5	133.4	<.001	.009	ns
Men (n=15)	727.6	197.4	584.5	229.3	475.5	174.3	492.6	205.1			
Aerobic capacity ($ml \cdot min^{-1} \cdot kg^{-1}$)[c]											
Women (n=13)	31.6	4.7	29.0	4.3	29.5	4.2	26.9	5.8	.001	ns	ns
Men (n=14)	33.2	5.6	34.1	5.3	31.7	8.7	28.8	5.4			

[a] Skinfolds of triceps and subscapular (mm)
[b] Distance between the 7th cervical spine and the 1st sacral spine (mm)
[c] Submaximal ergometer test.
ns = not significant, p > .05.

Objectively assessed, the men had higher workload than women, whereas subjectively the women perceived their workload higher than men. The means and standard deviations of different workloads by gender and differences between genders are presented in Table 2. (Studies III, IV)

5.1 Changes in physical capacity among ageing workers (Studies I and II)

During the follow-up periods, the average physical capacity of these workers decreased by approximately 0.9% per year. The studies showed that the greatest changes among men occurred in isometric trunk muscle and handgrip strength. Among the women the greatest decrease was in flexibility of spine, trunk extension strength (static and isometric), in squatting and in relative aerobic capacity. The smallest changes were noted in anthropometrics in both men and women. Among the men the annual decrease in physical capacity ranged from –2.1 to –0.7% and among the women the range was from –3.1 to –0.1%. Body mass index, thickness of skin folds and weight were the only variables which increased during follow-up. Annual changes in different components of physical capacity and different type of muscle work by gender are shown in Table 3. (Studies I, II)

The greatest differences in changes between genders were observed in isometric handgrip and trunk flexion strength. Among the men the decrease in handgrip strength was over six fold and in trunk flexion strength over twofold compared to the change among women. In relative aerobic capacity among women the annual decrease differed depending on the study. Among the women who worked at food industry the decrease was higher than among the municipal workers. (Table 3)

5.2 Changes in physical capacity between workers with different workloads (Studies II, III and IV)

In Study II there were no statistically significant differences among women in physical capacity between the physically demanding and mixed physically and mentally demanding workload groups. However, at the beginning of the follow-up period, the body mass index was higher among women in physical work than among women in mixed mentally and physically demanding work. In addition, the women in physical work had lower dynamic trunk flexion strength but better static and dynamic upper limb strength and better dynamic trunk extension strength than women in mixed work,

Table 2. Means and standard deviations (SD) of workload by gender in 1981 and differences between genders (p-value)

Workload	Mean	SD	p-value
Musculoskeletal load (0–70.7) [a]			
Women (n = 60)	14.1	5.3	.046
Men (n = 69)	16.3	6.1	
Cardiovascular strain (%HRR) [b]			
Women (n = 60)	20.9	9.6	.103
Men (n = 69)	23.6	10.7	
Perceived workload (RPE) [c]			
Women (n=58)	12.8	1.9	.75
Men (n= 64)	12.6	1.7	

a A sum of 17 different items which concerned physical demands at work

b The mean heart rate at work was individually related to the heart rate range. Relative heart rate range (%HRR) = 100 x (HR_{work} - HR_{rest}) / (HR_{max} - HR_{rest}). HR_{max} =[210 - (0.8 x age)].

c Perceived workload was assessed by the rating of perceived exertion (RPE, scale 6-20) on the scale developed by Borg (1970).

Table 3. Annual changes of anthropometrics and physical capacity variables (% / year) by gender

Variable	Change per year (%)	
	Women	Men
Anthropometrics		
Height	–0.1	0.0
Weight	0.4	0.3
BMI	0.5	0.4
Thickness of skin folds [a]	0.1	0.3
Flexibility of spine [b]	–1.7	–1.1
Upper limb strength		
Dynamic (repetitions) [c]	–3.1	
Static (s) [d]	–0.7	
Isometric handgrip strength (kPa)	–0.2	–1.3
Lower limb strength		
Squatting (repetitions) [c]	–3.0	
Trunk muscle strength		
Dynamic trunk flexion (repetitions) [c]	0.0	
Isometric trunk flexion strength (N)	–0.8	–2.1
Dynamic trunk extension strength (repetitions) [c]	–0.3	
Static trunk extension strength (s) [e]	–1.4	
Isometric trunk extension strength (N)	–1.4	–2.1
Relative aerobic capacity ($ml \cdot min^{-1} \cdot kg^{-1}$) [f]	–3.1 – –0.7	–0.7

Note: The variables which are only presented among women are the results of women in physically demanding work (Study II), except in relative aerobic capacity.

a Skinfolds of triceps and subscapular (mm)

b Distance between the 7th cervical spine and the 1st sacral spine (mm)

c Maximum result 50 repetitions

d Maximum result 90 s

e Maximum result 240 s

f Submaximal ergometer test

although the differences were not statistically significant. Instead, in 2000, the women in mixed mentally and physically demanding had better physical capacity than women with physical work, but the differences were not statistically significant. (Study II)

Generally, the physical capacity decreased more among women whose work was mainly physically demanding than among the women whose work was mixed mentally and physically demanding, although the differences were not statistically significant. The greatest differences in annual changes between women in physical work and women in mixed work were observed in the strength of the dynamic upper limbs (4.3% decrease vs. 2.4% decrease respectively) and in dynamic trunk extension strength (1.0% decrease vs. 2.9% increase respectively). (Study II)

In Studies III and IV the women with low workload also had better physical capacity in all measurements than the women with high workload. The only exception was handgrip strength in the last measurement where those women objectively assessed to have high workload, had better handgrip strength than the women with low workload. On the other hand, the men with low workload had better musculoskeletal capacity than the men with high workload at the end of follow-up. Instead, in aerobic capacity the men objectively assessed to have high workload, had better aerobic capacity at the end of follow up.

5.3 Differences in physical capacity among workers with objectively and subjectively assessed workload (Studies III and IV)

5.3.1 Differences in physical capacity

There were 22 subjects (18.0%) who perceived their workloads to be low but when the workload was assessed by the musculoskeletal-index they had high workload (RPE). In addition there were 21 subjects (17.2%) who perceived their workloads to be high but when assessed by musculoskeletal-index they had low workload.

There were differences in musculoskeletal capacity between workers with different workloads in association with the workload assessment method (musculo-skeletal-index or RPE-value). Among women there were statistically significant differences only in flexibility of the spine in 1985 ($p=.042$), in body mass index ($p=.042$) and in handgrip strength ($p=.011$) in 1997. The body mass index was higher and handgrip strength was better among those who perceived high workload but objectively assessed had low workload whereas flexibility of spine was better among women whose objectively and subjectively assessed workload was the same.

Among men there were more differences in musculoskeletal capacity between workers with different workloads based on different workload assessment method. There were statistically significant differences in isometric trunk extension strength in 1981 ($p=.035$) and in 1985 ($p=.011$) and in isometric trunk flexion strength in 1985 ($p=.043$). The men who perceived low workload in 1981 but had objectively assessed high workload, had better trunk muscle strength than the men who perceived high workload but objectively assessed had low workload. There were also differences in isometric trunk flexion ($p=.022$) and extension strength ($p=.049$) in 1981 and in handgrip strength ($p=.044$) in 1997 between the men who perceived low workload but objectively assessed had high workload compared with the men whose objectively and subjectively assessed workload was the same. The men whose objectively and subjectively assessed workload was the same had better isometric trunk muscle and handgrip strength than the men who perceived low workload but objectively assessed had high workload.

In addition there was a difference in body mass index ($p=.044$) between the men who perceived high workload but objectively assessed had low workload compared with the men whose objectively and subjectively assessed workload was the same. The men with the same objectively and subjectively assessed workload had higher body mass index than the men whose workload differed in association with assessment method of workload.

There were also differences between RPE and %HRR based grouping. Seven of the subjects (5.7%) who perceived low workload but had high workload as assessed by hear rate range. In addition there were 41 subjects (33.6%) who perceived their workload to be high but assessed by heart rate range had low workload. However, there were no statistically significant differences in aerobic capacity between subjects, either men or women, whose workloads differed compared with those whose workloads were the same when assessed by RPE and %HRR.

5.3.2 Incidence densities of poor and good physical capacity in different workload groups

There were some differences in incidences of poor and good physical capacity between workload groups in association with the workload assessment method. (Table 4) The greatest differences in improvements and declines of physical capacity between different workload groups based on different workload assessment method were observed in isometric trunk extension strength and in aerobic capacity. Among those who objectively assessed had low workload, the incidence of good isometric trunk extension strength (improvement compared with the subjects of the same age) was more common (44.2 vs. 23.8) than among the subjects who perceived low workload. This means that among the subjects whose objectively assessed workload was low improvement in isometric trunk extension strength was more common than among the subjects who perceived low workload. Instead the incidence of poor aerobic capacity (decrease compared with the subjects of the same age) among the subjects who perceived high workload was higher than among the subjects who objectively assessed had high workload (47.5 vs. 23.6). This means that among the subjects who perceived high workload the decline in relative aerobic capacity was more common than among the subjects whose objectively assessed workload was high. (Figures 6 and 7)

Table 4. Incidence density ratio of poor and good physical capacity per 1000 person years by different objective and perceived workload groups 1981–1997 (Studies III, IV).

Physical capacity variable	Objective workload[a]		Perceived workload [b]	
	High load	Low load	High load	Low load
Handgrip strength (kPa)				
Incidence of poor capacity	33.3	42.1	23.6	42.7
Incidence of good capacity	31.0	40.6	25.8	45.1
Flexibility of spine (mm)				
Incidence of poor capacity	27.4	31.9	40.8	22.1
Incidence of good capacity	29.2	40.6	35.6	32.5
Isometric trunk flexion (N)				
Incidence of poor capacity	30.6	35.3	27.8	32.3
Incidence of good capacity	23.1	47.2	33.3	29.1
Isometric trunk extension (N)				
Incidence of poor capacity	31.2	35.5	24.4	38.8
Incidence of good capacity	13.7	44.2	27.4	23.8
Aerobic capacity (ml • kg^{-1}• min^{-1})				
Incidence of poor capacity	23.6	32.1	47.5	29.9
Incidence of good capacity	15.0	36.5	30.9	32.8

a Assessing the musculoskeletal load used categorized musculoskeletal index and assessing cardiovascular strain (concerning only aerobic capacity variable) used categorized relative heart rate range (%HRR) = 100 x (HR_{work} - HR_{rest}) / (HR_{max} - HR_{rest}). HR_{max} =[210 - (0.8 x age)].

b Perceived workload was assessed by Borg scale (6-20) and categorized for two groups: low load ($RPE_{mean} \leq 12.5$ among women and $RPE_{mean} \leq 12.8$ among men) and high load ($RPE_{mean} > 12.5$ among women and $RPE_{mean} > 12.8$ among men)

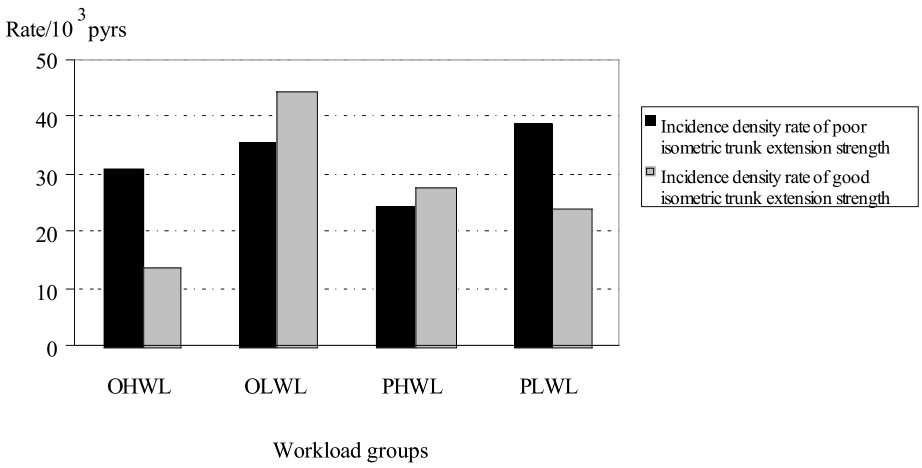

Figure 6. Incidence density of poor and good isometric trunk extension strength by different workload groups. OHWL = objectively assessed high workload, OLWL = objectively assessed low workload, PHWL = perceived high workload and PLWL = perceived low workload

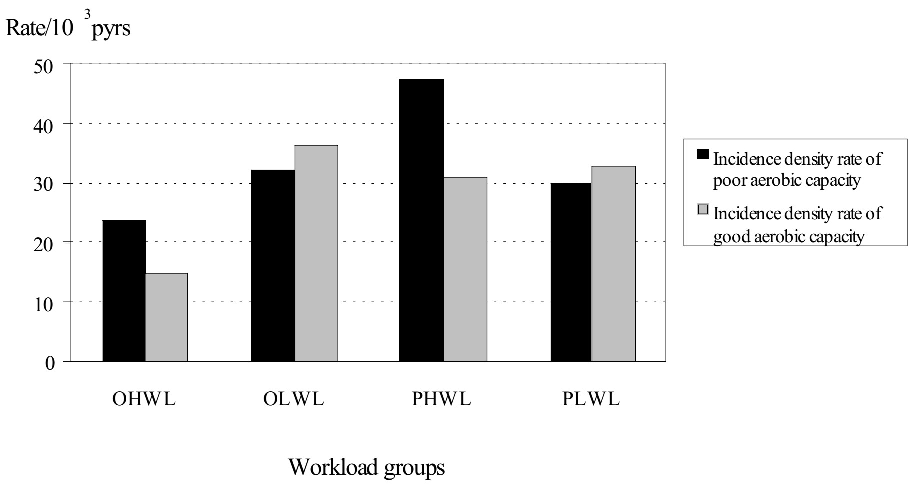

Figure 7. Incidence density of poor and good aerobic capacity by different workload groups. OHWL = objectively assessed high workload, OLWL = objectively assessed low workload, PHWL = perceived high workload and PLWL = perceived low workload

5.4 Physical capacity of the subjects who dropped out over the follow-up period

In the study on municipal employees, a total of four women and five men died during the follow-up period. (Figure 2) There were more men (n=23) than women (n=10) among dropout subjects in 1985. Not all the study subjects could take part in every physical capacity test because of different contraindications e.g. acute low back pain, heart dysfunction or medication affecting heart rate. The subjects who dropped out of the study sample between the years 1981 and 1985 did not participate in the aerobic capacity test in 1981 because they had some contraindication.

There were some differences in physical capacity between subjects who dropped out during follow-up and subjects who stayed in the sample for 16 years. Among men the flexibility of spine in 1981 was better among subjects who dropped out and in Study III they had more respiratory diseases than among subjects who continued the study. However, there were no differences in workload or in physical activity between the dropout subjects and the subjects who also participated in the follow-up in 1985.

Flexibility of the spine was now better among men who continued in the study compared to the men who dropped out. In Study IV the men who dropped out between 1985 and 1992 did not participate in the aerobic capacity tests in 1981 and in 1985.

The women who dropped out before 1992 had poorer isometric trunk extension strength in 1981 and had more cardiovascular diseases both in 1981 and 1985 than the women who continued in the study in 1992.

The men who dropped out before 1997 had poorer handgrip strength in 1985 than the men who participated to the study in 1997. In Study IV there were more men with high workload than with low workload (high 72.7% vs. low 27.3%) among the men who dropped out before 1997 (p=.044). Among the women there were no statistically significant differences in physical capacity and in workload between the dropout subjects and women who participated in follow-up in 1997. Besides, there were no differences in chronic diseases and physical activity levels between the dropout subjects and the subjects who participated in the study in 1997.

In Study II the non-participants and participants did not differ significantly for mean age, baseline physical capacity, physical activity and work demands. Instead, two thirds of the subjects (n=40) who participated in the follow-up measurements had at least one diagnosed disease compared to 46.8% (n= 22) of the dropout subjects (p=.051).

6 Discussion

6.1 Changes in physical capacity among ageing workers (Studies I and II)

Our results on men's body mass index are in agreement with those of Kuczmarski et al. (1994) finding that body mass index increased up to the fifth or sixth decade, after which it begins to decline. In the present study the decrease in BMI among men became observable between the third and the last measurement years when the men were 55–74 years old. However, body mass index increased among women during the follow-up period, believed to be a consequence of an increase in body weight and a decrease in stature. In addition, body mass index was higher among active groups than among the passive cohorts. People may have different body mass index, depending on their muscle mass and percent fat although they are the same size. Our result could not be explained by percent fat, because there were no differences in the thickness of skin folds between the active and the passive groups. However, the passive women and men gained more weight than the active women and men during the follow-up.

In the four-year follow-up of municipal employees, the sum of skin fold measurements decreased to a significant degree both in men and women (Nygård et al. 1991). After the entire study period of 16 years the sum of skin folds increased and women had thicker skin folds (more fat) than men. This finding is in agreement with the previous result, where women had significantly greater amounts of total body fat than men throughout the entire adult life span (Gallagher et al. 1996).

Our results concerning men's change in flexibility of the spine agree with the results of Stubbs et al. (1993) and McGregor et al. (1995). Instead, among women the decrease was more pronounced. One explanation might be that among women the decrease in height was greater than among men. One possible reason for this is osteoporosis. Another explanation might be that in women the ageing process affects the spine more than in men. A decrease in stature is part of the ageing process and is mainly a result of a reduction in the spinal vertebral body and disk space height (Sagiv et al. 2000).

Muscle strength

Although the short-term variations in strength fluctuated, the overall long-term trend with age was declining. In the present study the changes in handgrip strength were lower among both men and women compared to the follow-up study by Bassey (1998) and the cross-sectional study by Hunter et al. (2000). Among men, Rantanen et al. (1998) obtained comparable results in their 27-year follow-up study for handgrip strength among men aged 45–68 years. On the other hand, our changes among men were greater than in the study by Carmelli and Reed (2000). It has been reported that great inter-individual variations became evident when evaluating the decline of strength with increasing age. Likewise, for instance, over 30% of the variation in grip strength measured in old age may be explained by the strength of middle-aged people. (Rantanen et al. 1998.)

On average, men were stronger than women, whose strength amounted to 60–100% of the men's strength, depending on the muscle group. It has been suggested that women have less absolute muscle strength than men at all ages, which cannot be entirely accounted for by smaller body size (Bassey 1998). In Study I, the time dependent changes in female muscle strength were smaller than the changes among men, which confirmed the results of Metter et al. (1997), showing that women exhibit a less clear age-associated loss of strength than men.

It has been indicated that age-related decrease in isometric and dynamic muscle strength varied from 0.8–1.0% per year (Basu et al. 2002). Our results on women's isometric upper limb strength and dynamic trunk muscle strength agree with previous findings. Instead, among women the changes dynamic upper (–3.1%) and lower limb (–3.0%) and in isometric trunk extension strength (–1.4%) were greater. One reason for this might be that changes in dynamic upper and lower limb strength were expressed as medians because the variables were not normally distributed. However, our results are consistent with those of Nygård et al. (1991) on isometric trunk flexion strength among women and isometric trunk muscle strength among men and the results by Sörensen et al. (2000) on dynamic trunk muscle strength.

Aerobic capacity

In the four-year follow-up of municipal employees, aerobic capacity decreased by 6% among women, but increased by 8% among men. This was associated with an increase in leisure-time physical activity (Ilmarinen et al. 1991a). Regardless of the present 16-year study, aerobic capacity decreased equally among women and men and in general exceeded the research results of Paterson et al. (1999) reporting “normative” cardio-respiratory function data on men and women aged 55–86 years. The changes in aerobic capacity among men were similar to the results of the 15-year follow-up study by Sörensen et al. (2000) but were smaller than in the cross-sectional study by Paterson et al. (1999). Whereas among women the changes in aerobic capacity were equal to the findings of Paterson et al. (1999), they were smaller than the changes reported in the cross-sectional study by Tanaka et al. (1997). However, the average annual decline in aerobic capacity among women in physically demanding work was higher than previous follow-up studies (e.g. Pollock et al. 1997, Kasch et al. 1999, Sörensen et al. 2000). It has to be taken into account that only 14 women participated in both measurements, which may affect our results. In addition, it has also to be take into account that the annual change was based on medians of the subjects’ changes. We suggest, like Schibye et al. (2001), that the decrease in weight-related aerobic capacity with age is partly explained by an increase in the body mass index with increasing age.

According to Shephard (1999) there is good physiological reason (decrease in peak rates of ventilation, maximal cardiac output, maximal heart rate) to suggest that much of the loss of aerobic capacity is an inevitable consequence of the ageing process. Jackson et al. (1995), Proctor and Joyner (1997) and Schibye et al. (2001) have proposed that half of the age-related decrease in aerobic power could be attributed to age-associated changes in body composition, including increased BMI, body fat and loss of lean muscle mass and a decrease in habitual physical activity. Moreover, Shephard (1984) emphasises that intra-individual day-to-day variation in aerobic capacity may vary between 4% and 6%. It should be noted, however, that the results may also be influenced not only by testing methods and measurers but also by individual factors like motivation and pain.

In our study individual variations were wider among women than men in almost all variables of physical capacity except body mass index. Moreover, not all subjects had undergone changes, which may be explained by a subject having or not having pain or an acute disease affecting the results at the time of measurement. Another explanation for such notable individual variations may be the changes in leisure-time physical activities, as the women especially increased their physical activity after retirement, probably because they had more spare time.

The annual changes in physical capacity were neither linear nor consistent, yet they varied between genders, different physical capacity variables, and different measurement times during the study period. There may be many reasons for this finding, one being the changes in people's state of health and physical activities between measurement times. Another reason may be the repeatability of measuring methods, as not all methods are equally reliable. Finally, people's own motivations have an important effect on these results and should also be recognized.

6.2 Changes in physical capacity in relation to different workloads (Studies II, III and IV)

In general, physical workloads have been higher among men than among women at younger ages, but the difference was less pronounced at higher ages (Torgèn and Kilbom 2000). Our results partly confirmed the results by Torgèn and Kilbom (2000). Therefore, in the present study, the men had higher musculoskeletal and cardiovascular load than women, whereas perceived workload was higher among the women.

In the present study both physical activity and the proportion of subjects who had some chronic disease increased. There were no differences in physical activity between different workload groups. The increase in the proportion and in number of chronic diseases concurs with those reported in previous studies (Sörensen et al. 2000, Pohjonen 2001) The women with high workload had more diagnosed diseases than women with low workload at the beginning of follow-up. This difference may partly explain why physical capacity among women with high workload was poorer than among women with low workload in the beginning of follow-up.

In general, physical capacity was poorer among the subjects with high workload than among the subjects with low workload, especially among the women. This finding concurs with the previous follow-up study by Nygård et al. (1994). The greatest differences between the workload groups were observed in the changes of isometric trunk extension strength and in aerobic capacity. One reason for this might be that the subjects within the different workload groups are more heterogeneous in these components than in other components of physical capacity. The worker with physically low workload will manage in his / her work regardless of the poor muscle strength or aerobic capacity, whereas in physically demanding work this is not possible.

In addition, among the low workload group the change from good to poor physical capacity category, which was based on the results from the study subjects, was more common than among workers with high workload. One of the reasons could be that there were more workers with low workload than workers with high workload in the good physical capacity category at the beginning of follow-up. There were more workers with low workload at risk for decline of physical capacity. On the other hand, workers with low workload improved their physical capacity more often than workers in high workload groups, especially in isometric trunk muscle strength and in aerobic capacity. One reason for this could be that the low workload group may have been more heterogeneous in their physical capacity compared with the high workload group. Another reason could be that severe musculoskeletal or cardiovascular disorders increased more among the subjects with high workload than among the low workload group.

On the other hand, in the study by Torgén et al. (1999a) on 484 middle-aged men and women from the general population, no significant effect modification by age, exercise, smoking habits or musculoskeletal status was observed in the relationship between physical workload level and different measures of physical capacity. In Study II there were no differences in age, body mass index and physical activity between different workload groups. Instead, at the time of the test in 1981, the women with high workload had more musculoskeletal diseases compared with the women with low workload. This finding confirms previous results where the women with high job demands had poorer general health, poorer psychological well-being and more musculoskeletal symptoms than the women with low job demands. Among men there were no differences in self-reported health status between different workload groups. (Karlqvist et al. 2003b.)

Muscle strength

Our findings are in agreement with the results of the studies by Torgén et al. (1999a) and Schibye et al. (2001) as regards better static upper limbs and dynamic trunk extension strength among women in physical work than among women in mixed work at the beginning of follow-up. It has been reported earlier that upper limb strength was good among those with high physical workloads (Torgén et al. 1999a, Schibye et al. 2001). Our results concerning perceived workload and handgrip strength agree with these study results. Instead the workers with low workload, assessed by musculoskeletal index, had better handgrip strength than the workers with high workload at the beginning of follow-up but poorer handgrip at the end of follow-up. This finding concurs the previous study, in which the women in the youngest age group with the highest job demands had significantly greater handgrip strength than women in the oldest age group with the same job demands. (Karlqvist et al. 2003b.)

It has been suggested that workers with low workload showed better muscle performance in squatting, sit-up, arch-up and back endurance (Alaranta et al. 1994a, Karlqvist et al. 2003b). Our results are consistent with these results. In the present study the women with low workload had better isometric trunk muscle strength than the women with high workload in all measurements. In addition, the women with mixed physical and mental work had better squatting and dynamic trunk muscle strength than the women with physical work at the end of the follow-up. The men with low workload had lower trunk muscle strength than the men with high workload in the beginning of follow-up. However, at the end of the study period the men with low workload had better trunk muscle strength than the men with high workload. On the other hand, in Studies III and IV, the decline in isometric trunk muscle strength was more common among the low workload group than among the high workload group. One explanation for our findings may be either that a worker perceived his / her workload to be physically heavy because of his / her poor muscle strength or that physically heavy work has a greater wearing effect on muscle strength than physically light work. Previous findings on objectively measured workload and changes in physical capacity support the latter explanation (Nygård et al. 1991). Thus, like Alaranta et al. (1994a) and Torgén et al. (1999a) we suggest that high physical demands in a job have a possible wearing effect on the trunk muscles and lower extremities.

It has been proposed that a rather steep decline in muscle strength in a physical work group may imply a combination of an age-related decline of strength and a wearing effect. This could be due to a job type often characterized by a high degree of repetitive, monotonous movements. (Schibye et al. 2001.) This could also be one explanation for our findings, because the work of the subjects in Study II involved a lot of standing, repetitive and monotonous movements and carrying or lifting of heavy loads.

Aerobic capacity

Tammelin (2003) find out that a high level of occupational physical activity was associated with high level of cardiorespiratory fitness in males and female aged 31 years. However, our results concurred partly with the results of Torgén et al. (1999a), Schibye et al. (2001) and Karlqvist et al. (2003b) that physical work has no training effect on aerobic capacity among ageing subjects. In the present study, the aerobic capacity ($l \cdot min^{-1}$) was lower among the high workload group than among the low workload group, although the differences were not statistically significant. At the end of follow-up the men with low workload had lower related aerobic capacity ($ml \cdot min^{-1} \cdot kg^{-1}$) than men with high workload. One explanation for this may be that men with low workload gained more body weight than the men with high workload over the follow-up period. The other explanation may be the selection factor, which suggests that the workers still doing their jobs are those who can still meet the physical demands of the job resulting in a greater aerobic capacity for these individuals.

It is very difficult to explain why occupational physical activity does not maintain or increase physical capacity contrary to physical activity during leisure. One of the reasons could be that the occupational activity does not include training elements in the right proportions. That is the level, frequency, duration and type of the activity is not the best way to increase capacity. (Nygård et al. 1994.) For ageing workers sufficient pauses during work tasks are required because the exertion accumulates and the weekends are not enough for recover from strenuous work.

6.3 Differences in physical capacity among workers with objectively and subjectively assessed workload (Studies III and IV)

The greatest differences in physical capacity between workers with different workloads in association with the different workload assessment methods were in improvement of isometric trunk extension strength and in decline of aerobic capacity. Among the subjects whose workload was objectively assessed to be low, improvement in isometric trunk extension was more common than among the subjects who perceived their workload to be low. One explanation for this might be that the group who perceived low workload was more heterogeneous regarding their muscle strength than the other group. The other reason might be that the subjects who perceived low workload already belonged to the good isometric trunk extension group at the beginning of follow-up, so they could not change their category although their strength improved.

On the other hand the decline in aerobic capacity was more common among the subjects who perceived high workload than among the subjects whose cardiovascular strain was high. One reason might be that the ratings of perceived exertion measure overall exertion, also including mental load not only musculoskeletal or cardiovascular system load. The subjects who perceived their workload to be high could have work which does not overstrain the aerobic capacity compared to the subjects whose work has assessed as high workload by heart rate range (%HRR).

In addition, there were differences in musculoskeletal capacity between workers with different workloads in association with different workload assessment methods. Among women the differences in musculoskeletal capacity between the subjects whose workloads were different if the workload was assessed objectively or subjectively were less than among men. Instead, men who perceived low workload but objectively assessed had high workload had better muscle strength than those whose objectively and subjectively assessed workload was the same. One possible explanation might be that the men rated their exertion at work in relation to their musculoskeletal capacity, whereas the women rated their exertion in relation to their basic ability to do work, which also include the social and mental aspects. The other reason for this might be the difference in men's and women's type of work. For example, it has been observed that women who had high job demands had more time-bound work compared to men with high job demands. Besides, when workers were unable to choose their own work pace, the relative workload varied inversely with work capacity. (Karlqvist et al. 2003a.)

However, there were no differences in aerobic capacity between different workload groups in association with the workload assessment method. Our finding contradicts with the earlier finding where Karlqvist et al. (2003a) indicated that work exposures are strongly related to an excess metabolic level. One reason for our result might be that the aerobic capacity could not be measured for all the subjects because of contraindications. There may have been some subjects who perceived high workload but had low workload as assessed by heart rate range who did not participate in the aerobic capacity tests at all.

6.4 Methodological considerations

In this study, data are presented from four different longitudinal studies although the original sample of Studies I, III and IV was the same. In Study I the study design was the strictest, because the subjects included in this study had to participate in all measurements, which were implemented in 1981, 1985, 1991 and in 1997. This is the reason why the number of the study subjects shrank eventually to quite a small sample size.

Longitudinal studies are usually affected by withdrawal, survival and refusal biases (Desrosiers et al. 1998). Accordingly, the shrinkage of samples during the follow-up period is a major problem in studies extending over many years. We therefore had a small sample of the original population and this may have biased our findings. There were differences in physical capacity (e.g. aerobic capacity) and diseases between dropout subjects and subjects who participated to the follow-up studies. This may have affected the results since the fitter, healthier, and better-motivated subjects may have participated in measurements.

However, Desrosiers et al. (1998) and Torgén et al. (1999a) have concluded that a cross-sectional study design underestimates changes with age when compared to a longitudinal design, but our results can only partly confirm this. In addition, to evaluate the intra-individual changes in strength over time the only option is to measure the physical capacity at the beginning and at the end of follow-up (de Zwart et al. 1995). In

Study I we could also observe the variation in physical capacity during the follow-up period because we had four different measurement points.

Usually, the requirement for homogeneity and contrast in the comparison of differentially exposed occupational groups constitutes an important methodological criterion (Fallentin et al. 2001). In the present study homogeneity of subjects was attained, since the mean age of the workers was almost the same in the different workload groups. Moreover, the difference in workload enabled comparisons between different workload groups. A particular advantage of the present study is that in addition to the different assessments of workload [musculoskeletal-index, heart rate range (Study III) and perceived workload (Studies II and IV)] data we also measured different components of physical capacity and different types of muscle work.

Assessments of physical capacity

In the present study, the assessment of physical capacity included different kinds of musculoskeletal and cardiovascular capacity measurements. The methods used in testing muscle strength in Study II, had fairly high one-year intra-observer reproducibility (0.63–0.87) and the inter-observer reliability coefficients (0.66–0.95) were also fairly good or excellent (Alaranta et al. 1994a). The reliability of the musculoskeletal capacity measurements (Studies I, III and IV) was also fairly good (Nygård et al. 1988).

In addition the reliability of the submaximal exercise test before and after the four year follow-up was also evaluated. (Ilmarinen et al. 1991a.) These test-retest measure-ments showed that the reliability of the physical capacity tests is acceptable.

Assessment of workload

There could be many problems in assessing workers' workload for study purposes. In follow-up studies, a baseline exposure assessment is often available, and then the cohort is followed with regard e.g. to physical capacity. One limitation of this strategy is that changes in exposure status during follow-up lead to biased estimates for the risks. (Köster et al. 1999.) In Studies III and IV, the workload was assessed at the beginning of follow up. However, Nygård et al. (1999) studied the changes in work demands among our study subjects or their successors during the follow-up period. Their results were based on an expert rating of jobs and suggested that no remarkable changes in work demands occurred among the studied sample of municipal workers in Finland between 1981 and 1993. (Nygård et al. 1999.) In addition, the occupational stability was high in the present study; only a few of the subjects changed their occupational status or workplace during the follow-up periods. The subjects who changed their workplace remained in the similarly straining occupations, thus the exposure to work did not change over time.

In the assessment method of musculoskeletal workload (Study III), the individual analyses of the observers were compared to the reference analysis done afterwards by a teacher and five observers together. Inter-tester reliability was good. The results showed that the number of uniform classifications of the items varied from 75% to 89% (Ilmarinen et al. 1991b).

In general, direct measurements or systematic observations at the workplace are recommended in preference to questionnaire-based information. However, exposures occurring in the past are often no longer available for observation (Torgèn et al. 1999b). In Study II, occupational exposure was elicited by one question of a very basic nature. It is assumed that people in general remember and can evaluate their main work demands well. In addition, all the subjects perceived their work demands to be the same at the end as in the beginning of the follow-up.

In order to judge the reliability of a workload assessment method, it should be applied to jobs with a wide distribution of exposures across the range of possible values (Burt and Punnett 1999). The subjects in the present study represented several occupational groups, with different exposures.

Above all, a major problem in physical exposure assessment concerns the variability in exposure between workers performing the same job. Some individuals stay healthy even after long-term exposure. The reasons for this discrepancy may be either differences in susceptibility or differences in individual exposure. (Balogh et al. 1999.) According to the study by Nordander et al. (2000), on female hospital cleaners and male and female office workers aged 26–63 years, some of the inter-individual variance in exposure was explained by body mass index and age. Furthermore, Fallentin et al. (2001) concluded in their study, which covered 3123 workers from 19 different factories representing a variety of industries, that individual work technique and anthropometrics are stronger determinants of exposure than task characteristics or exposure group membership. In Study II, we compared women working at the same factory. The women perceived their workload differently although their work could be classified as physically demanding. This difference in perceived workload could be explained by the differences in physical capacity.

For each exposure it is important to assess both the dimensions of intensity and time. In addition, the amount of time spent in recreation and other activities outside work can modify the effects of workplace exposures (Hagberg et al. 2001). In Study III, we took into account the time, frequency and intensity of the particular load but we did not consider the load of activities outside work (e.g. household chores, child care), which may have affected our results concerning workload category and differences between load categories.

Data analysis

In a study with multiple dependent and independent variables multivariate analysis would be appropriate, but our sample size was too small for this type of analysis. Instead, our method of analysis (Studies III, IV), which is more common in epidemiological studies, was very useful in this study. With this method as a basis we could use the data on all the subjects who took part in at least two measurements and we could analyse women and men together. In addition, the comparison between the results of Studies III and IV became possible. However, as Hjelm et al. (1995) emphasise, the misclassification of exposure, as well as the outcome, is always a problem in epidemiological studies. This is equally severe when the misclassification is independent of the outcome as in musculoskeletal load. In our study the categories of musculoskeletal and perceived workload and physical capacity were based on the results on the subjects for the variable since there were no theoretical cut points for low or high workload of musculoskeletal system, perceived exertion or for good or poor physical capacity among these middle-aged people. If the cut points were changed, the results could have been different, too.

7 Summary and conclusions

The main findings of the present study were the following:

1) Age-related decline in physical capacity was on average 0.9% per year. However, there were differences in annual changes between different components of physical capacity, different muscle groups and different types of muscle work. The greatest changes were observed in handgrip and trunk muscle strength among men and among women in flexibility of spine, trunk muscle strength, in limbs endurance and in aerobic capacity. The smallest changes were found in anthropometrics both among women and men. The decrease of physical capacity was greater among men than among women, although women had more individual variations. (Studies I, II)

2) Among women the differences between high and low workload groups were more evident than among men. In general, women with low workload had better physical capacity than women with high workload at the end of the follow-up period. In addition, men with low workload had better musculoskeletal capacity compared with men with high workload. Compared with subjects of the same age both improvements and declines in physical capacity were observed. Both declines and improvements among the subjects with low workload were more common than among the subjects with high workload in general. (Studies II, III, IV)

3) Differences in physical capacity between workers with different workloads were associated with the workload assessment method, especially among men. Among women the differences in physical capacity between different workload groups were minor. Instead among men who perceived high workload but objectively assessed had low workload, had poorer muscle strength than those men whose objectively and subjectively assessed workload was the same. (Studies III, IV)

It was concluded that age-related decline in physical capacity was observed. The annual changes in physical capacity depended on the components of physical capacity. Compared with subjects of the same age improvements in physical capacity were also observed. In addition there were differences in physical capacity in relation to workload. However, the differences in physical capacity between different workload groups were associated with the method of assessing workload, especially among men. It also has to be considered that a worker with poor physical capacity may perceive his/her physical workload as high although he/she has as objectively assessed physically low workload. These results permit the conclusion that physically demanding work may not maintain or improve physical capacity among ageing workers.

To avoid increased relative workloads among elderly workers it is necessary to reduce the work demands imposed on the elderly worker and / or maintain or improve their physical capacity. In practice this means that working life needs to be individually adjusted to these changes in physical capacity by lowering the physical demands of the work e.g. by shorter working hours (duration) which promotes recovery from strenuous work tasks, ergonomically designed work tools and instruments (intensity). In addition the worker must have opportunities to regulate her / his own work e.g. alters and adjusts different work tasks, methods and speed (type and frequency). At the same time, if the physical capacity of the workers improves, they may perceive their workload to be physically lighter than before.

8 Acknowledgements

The present work was carried out at the Tampere School of Public Health, University of Tampere, Finland, in collaboration with the Department of Physiology, Finnish Institute of Occupational Health and Tampere Occupational Health Centre.

I deeply grateful to my supervisor, Professor Clas-Håkan Nygård, PhD, for his valuable opinions and suggestions during this work, and especially for his support and encouragement. He believed that some day this dissertation would be completed when I did not believe it myself.

I am indebted to Docent Taina Rantanen, PhD, and Docent Juha Oksa, PhD, for their constructive criticism, careful review of the manuscript and valuable advice in the final stages of the preparation of this dissertation.

I wish to thank Professor Matti Hakama DSc, friends Heini Huhtala MSc and Annukka Koivisto BSc, for their invaluable and patient assistance in planning and explaining the statistical analyses. I am very grateful to my co-authors Professor Juhani Ilmarinen, PhD, Olli Korhonen, PhD, MD and Docent Heikki Arola, PhD, MD, for their comments on the drafts of the original articles.

I am grateful to my friends and colleagues, especially to Ilona Kulmala MSc, Miia Artama MSc, Marita Pitkänen MSc and Paula Salonen MSc for friendship, our many enlightening discussions on the “meaning of it all” and for walking along. I also wish to thank all the people working at Tampere School of Public Health and especially PG for their support and the most enjoyable working atmosphere. I owe my thanks to Ms Marita Hallila for editing the layout of this dissertation. Moreover I thank Virginia Mattila MA for revising the English language very rapidly and efficiently. I have learnt a lot from her.

Furthermore, I would like to thank a number of people who have contributed to this work. I warmly thank all the volunteer subjects who participated in the studies and made this work possible for their patience and co-operation.

My deepest gratitude to my family, my dear husband Kimmo and daughter Emma, for their constant love, support and for showing me what is important in life. I also express my warm thanks to my dear mother and sister Tiina. Without your support and confidence this work would have been considerably more difficult.

The financial support of Doctoral Programs of Public Health, the Pirkanmaa Regional Fund of the Finnish Cultural Foundation and the Juho Vainio Foundation are gratefully acknowledged.

Tampere, June 19th 2004

Minna Savinainen

9 References

Alaranta H, Hurri H, Heliövaara M, Soukka A and Harju R (1994a): Non-dynamic trunk performance tests: reliability and normative data. Scand J Rehab Med 26: 211–215.

Alaranta H, Hurri H, Heliövaara M, Soukka A and Harju R (1994b): Flexibility of the spine: normative values of goniometric and tape measurement. Scand J Rehab Med 26: 147–154.

American Academy of Orthopaedic Surgeons (1965): Joint motion – methods of measuring and recording. London: American Academy of Orthopaedic Surgeons.

Aminoff T, Smolander J, Korhonen O and Louhevaara V (1996): Physical work capacity in dynamic exercise with differing muscle masses in healthy young and older men. Eur J Appl Physiol 73: 180–185.

Aminoff T, Smolander J, Korhonen O and Louhevaara V (1999): Physiological strain during kitchen work in relation to maximal and task-specific peak values. Ergonomics 42: 584–592.

Anil M and Shrawan K (1998): Human muscle strength definition, measurement, and usage: Part I – Guidelines for practitioner: Int J Ind Ergon 22: 101–121.

Asmussen E, Heebøll-Nielsen K and Mollbech SV (1959): Methods for evaluating of muscular strength. Communications from the Testing and Observation Institute of the Danish National Association for Infantile Paralysis 5, Hellerup (Denmark): Institute of the Danish National Association for Infantile Paralysis.

Balogh I, Hansson G-Å, Ohlsson K, Strömberg U and Skerfving S (1999): Interindividual variation of physical load in a work task. Scand J Work Environ Health 25: 57–66.

Bassett DR and Howley ET (2000): Limiting factors for maximum oxygen uptake and determinants of endurance performance. Med Sci Sports Exerc 32: 70–84.

Bassey EJ (1998): Longitudinal changes in selected physical capabilities: muscle strength, flexibility and body size. Age Ageing 27 (Suppl 3): 12–16.

Basu R, Basu A and Nair KS (2002): Muscle changes in aging. J Nutr Health Aging 6: 336–341.

Baumgartner RN, Waters DL, Gallagher D, Morley JE and Garry PJ (1999): Predictors of skeletal muscle mass in elderly men and women. Mechanism of Ageing and Development 107: 123–136.

Boos N, Weissbach S, Rohrbach H, Weiler C, Spratt KF and Nerlich AG (2002): Classification of age-related changes in lumbar intervertebral discs: 2002 Volvo Award in basic science. Spine 27: 2631–2644.

Borg G (1970): Perceived exertion as an indicator of somatic stress. Scand J Rehab Med 2: 92–98.

Bunce D and Sisa L (2002): Age differences in perceived workload across a short vigil. Ergonomics 45: 949–960.

Burt S and Punnett L (1999): Evaluation of interrater reliability for posture observations in a field study. Appl Ergon 30: 121–135.

Bäckman E, Johansson V, Häger B, Sjöblom P and Henriksson KG (1995): Isometric muscle strength and muscular endurance in normal persons between 17 and 70 years. Scand J Rehab Med 27: 109–117.

Carmelli D and Reed T (2000): Stability and change in genetic and environmental influences on hand-grip strength in older male twins. J Appl Physiol 89: 1879–1883.

de Zwart BCH, Frings-Dresen MHW and van Dijk FJH (1995): Physical work load and the aging workers: A review of the literature. Int Arc Occup Environ Health 68:1–12.

Desroiers J, Hebert R, Bravo G and Rochette A (1998): Comparison of cross-sectional and longitudinal designs in the study of aging of upper extremity performance. J Gerontol: A Biol Med Sci 53A: B362–368.

Ensink FB, Saur PM, Frese K, Seeger D and Hildebrandt J (1996): Lumbar range of motion: influence of time of day and individual factors on measurements. Spine 21: 1339–1343.

Era P and Rantanen T (1997): Changes in physical capacity and sensory / psychomotor functions from 75 to 80 years of age and from 80 to 85 years of age – a longitudinal study. Scand J Soc Med 53 (Suppl): 25–43.

Era P, Schroll M, Hagerup L and Schultz-Larsen Jürgensen K (2001): Changes in bicycle ergometer test performance and survival in men and women from 50 to 60 and from 70 to 80 years of age: two longitudinal studies in the Glostrup (Denmark) population. Gerontology 47: 136–144.

Eskurza I, Donato AJ, Moreau KL, Selas DR and Tanaka H (2002): Changes in maximal aerobic capacity with age in endurance-trained women: 7-yr follow-up. J Appl Physiol 92: 2303–2308.

Fallentin N, Juul-Kristensen B, Mikkelsen S, Andersen JH, Bonde JP, Frost P and Endahl L (2001): Physical exposure assessment in monotonous repetitive work – the PRIM study. Scand J Work Environ Health 27: 21–29.

Frontera WR, Hughes VA, Fielding RA, Fiatarone MA, Evans WJ and Roubenoff R (2000): Aging of skeletal muscle: a 12-yr longitudinal study. J Appl Physiol 88: 1321–1326.

Fujiwara A, Tamai K, Yamato M, An HS, Yoshida H, Saotome K and Kurihashi A (1999): The relationship between facet joint osteoarthritis and disc generation of the lumbar spine: an MRI study. Eur Spine J 8: 396–401.

Gallagher D, Visser M, Sepúlveda D, Pierson RN, Harris T and Heymsfield SB (1996): How useful is body mass index for comparison of body fatness across age, sex, and ethnic group? Am J Epidem 143: 228–239.

Giampaoli S, Ferrucci L, Cecchi F, Lo Noce C, Poce A, Dima F, Santaquilani A, Vescio M and Menotti A (1999): Hand-grip strength predicts incident disability in non-disabled older men. Age and Ageing, 28: 283–288.

Greig CA, Botella J adn Young A (1993): The quadriceps strength of healthy elderly people remeasured after eight years. Muscle Nerve 16: 6–10.

Hagberg M, Punnett L, Bergqvist U, Burdof A, Härenstam A, Kristensen TS, Lillienberg L, Quinn M, Smith TJ and Westberg H. (2001): Broadening the view of exposure assessment. Consensus reports. Scand J Work Environ Health 27: 354–357.

Hamerman D (1998): Biology of the aging joint. Clin geriatr med 14: 417–433.

Hansson G-Å, Balogh I, Byström JU, Ohlsson K, Nordander C, Asterland P, Sjölander S, Rylander L, Winkel J and Skerfving S (2001): Questionnaire versus direct technical measurements in assessing postures and movements of the head, upper back, arms and hands. Scand J Work Environ Health 27: 30–40.

Hansson G-Å, Balogh I, Ohlsson K, Pålsson B, Rylander L and Skerfving S (2000): Impact of physical exposure on neck and upper limb disorders in female workers. Appl Ergon 31: 301–310.

Hasten DL, Lea RD and Johnston FA (1996): Lumbar range of motion in male heavy laborers on the Applied Rehabilitation Concepts (ARCON) system. Spine 21: 2230–2234.

Hjelm EW, Winkel J, Nygård C-H, Wiktorin C, Karlqvist L and Stockholm MUSIC 1 Study Group (1995): Can cardiovascular load in ergonomic epidemiology be estimated by self-report? JOEM 37: 1210–1217.

Hoogendoorn WE, van Poppel MNM, Bongers PM, Koes BW and Bouter LM (1999): Physical load during work and leisure time as risk factors for back pain. Scand J Work Environ Health 25: 387–403.

Hunter GR, Newcomer BR, Weinsier RN, Karapondo DL, Larson-Meyer DE, Joanisse DR and Bamman MM (2002): Age is independently related to muscle metabolic capacity in premenopausal women. J Appl Physiol 93: 70–76.

Hunter SK, Thompson MW and Adams RA (2000): Relationships among age-associated strength changes and physical activity level, limb dominance, and muscle group in women. Journal of Gerontology: Biological Sciences 55A: B264–B273.

Ilmarinen J (1978): Beziehungen zwischen beruflicher und sportlicher körperlicher Aktivität und kardiopulmonaler Leistungsfähigkeit (Dissertation). Köln, Deutsche Sporthochschule.

Ilmarinen J (1992): Job design for the aged with regard to the decline in their maximal aerobic capacity: Part II. The scientific basis for the guide. Int J Ind Ergomics 10:65–77.

Ilmarinen J (1999): Ageing workers in the European Union – Status and promotion of work ability, employability and employment. Finnish Institute of Occupational Health, Ministry of Social Affairs and Health, Ministry of Labor, Helsinki.

Ilmarinen J (2001): Functional capacities and work ability as predictors of good 3rd age. In: Physical Fitness and Health Promotion in Active Aging, pp. 61–80. Eds. K Shiraki, S Sagawa and MK Yousef, Backhuys Publishers, Leiden, Netherlands.

Ilmarinen J, Louhevaara V, Korhonen O, Nygård C-H, Hakola T and Suvanto S (1991a): Changes in maximal cardiorespiratory capacity among aging municipal employees. Scand J Work Environ Health 17 (Suppl 1): 99–109.

Ilmarinen J, Suurnäkki T, Nygård C-H and Landau K (1991b): Classification of municipal occupations. Scand J Work Environ Health 17 (Suppl 1): 12–29.

Ilmarinen, J, Tuomi K, Eskelinen L, Nygård C-H, Huuhtanen P and Klockars M (1991c): Background and objectives of the Finnish research project on aging workers in municipal occupations. Scand J Work Environ Health 17 (Suppl 1):7–11.

Jackson AS, Beard EF, Wier LT, Ross RM, Stuteville JE and Blair SN (1995): Changes in aerobic power of men ages 25–70 yr. Med Sci Sports Exerc 27:113–120.

Janssen I, Heymsfield SB, Wang Z and Ross R (2000): Skeletal muscle mass and distribution in 468 men and women aged 18–88 yr. J Appl Physiol 89: 81–88.

Karlqvist L, Härenstam A, Lejon O, Schéele P and the MOA Research Group (2003a): Excessive physical demands in modern worklife and characteristics of work and living conditions of persons at risk. Scand J Work Environ Health 29: 363–377.

Karlqvist L, Lejon O and Härenstam A (2003b): Physical demands in working life and individual physical capacity. Eur J Appl Physiol 89: 536–547.

Kasch FW, Boyer JL, Schmidt PK, Wells RH, Wallace JP, Verity LS, Guy H and Schneider D (1999): Ageing of the cardiovascular system during 33 years of aerobic exercise. Age Ageing 28: 531–536.

Kent-Braun JA and Ng AV (2000): Skeletal muscle oxidative capacity in young and older women and men. J Appl Physiol 89: 1072–1078.

Keys A, Fidanza F, Karvonen M, Kimura N and Taylor H (1972): Indices of relative weight and obesity. J Chron Dis 25: 329–343.

Kuczmarski RJ, Flegal KM, Campbell SM and Johnson CL (1994): Increasing prevalence of overweight among US adults. The National Health and Nutrition Examination. JAMA 272: 205–211.

Kumashiro M (2000): Ergonomics strategies and actions for achieving productive use of ageing work-force. Ergonomics 43: 1007–1018.

Köster M, Alfredsson L, Michélsen H, Vingård E and Kilbom Å (1999): Retrospective versus original information on physical and psychosocial exposure at work. Scand J Work Environ Health 25: 410–414.

Landers KA, Hunter GR, Wetzstein CJ, Bamman MM and Weinsier RL (2001): The interrelationship among muscle mass, strength, and the ability to perform physical tasks of daily living in younger and older women. J Ger: Biol Sci 56A: B443–B448.

Lexell J (1995): human aging, muscle mass, and fiber type composition. J Gerontol A Biol Sci Med Sci 50: 11–16.

Lindle RS, Metter EJ, Lynch NA, Föeg JL, Fozard JL, Tobin J, Roy TA and Hurley BF (1997): Age and gender comparisons of muscle strength in 654 women and men aged 20-93 yr. J Appl Physiol 83: 1581–1587.

Louhevaara V (1999): Is the physical work load equal for ageing and young blue-collar workers? Int J Ind Erg 24: 559–564.

Louhevaara V, Ilmarinen J and Oja P (1980). Comparison of the Åstrand nomogram and the WHO extrapolation methods for estimating maximal oxygen uptake. Scand J Sports Sci 2: 21–25.

Lynch NA, Metter EJ, Lindle RS, Fozard JL, Tobin JD, Roy TA, Fleg JL and Hurley BF (1999): Muscle quality. I. Age-associated differences between arm and leg muscle groups. J Appl Physiol 86:188–194.

McGregor AH, McCarthy ID and Hughes SP (1995): Motion characteristics of the lumbar spine in the normal population. Spine 20: 2421–2428.

Metter EJ, Conwit R, Tobin J and Fozard JL (1997): Age-associated loss of power and strength in the upper extremities in women and men. J Ger: Biol Sci 52A: B267–B276.

Miller AE, MacDougall JD, Tarnapolsky MA and Sale DG (1993): Gender differences in strength and muscle fiber characteristics. Eur J Appl Physiol Occup Med 66: 254-262.

Miyatake N, Fujii M, Nishikawa H, Wada J, Shikata K, Makino H and Kimura I (2000): Clinical evaluation of muscle strength in 20–79-years-old obese Japanese. Diabetes Res Clin Pract 48: 15–21.

Mokdad M (2002): Anthrpometric study of Algerian farmers. Int J Ind Erg 29: 331–341.

Narici MV, Maganaris CN, Reeves ND and Capodaglio P (2003): Effect of aging on human muscle architecture. J Appl Physiol 95: 2229–2234.

Nevill AM and Holder RL (2000): Modeling handgrip strength in the presence of confounding variables: results from Allied Dundar National Fitness Survey. Ergonomics 43: 1547–1558.

Nordander C, Hansson G-Å, Rylander L, Asterland P, Byström JU, Ohlsson K, Balogh I and Skerfving S (2000): Muscular rest and gap frequency as EMG measures of physical exposure: the impact of work tasks and individual related factors. Ergonomics 43: 1904–1919.

Nygård C-H, Luopajärvi T and Ilmarinen J (1988): Musculoskeletal capacity of middle-aged women and men in physical, mental and mixed occupations. A 3.5-year follow-up. Eur J Appl Physiol Occup Med 57: 181–188.

Nygård C-H, Luopajärvi T and Ilmarinen J (1991): Musculoskeletal capacity and its changes among aging municipal employees in different work categories. Scand J Work Environ Health 17 (Suppl 1): 110–117.

Nygård C-H, Suurnäkki T and Ilmarinen J (1999): Job demands of ageing employees over 12-year period. In FinnAge – Respect for the aging: Action programme to promote health, work ability and well-being of aging workers in 1990–96. In: People and work, pp. 251–259. Eds. J Ilmarinen, and V Louhevaara, Research reports 26. Finnish Institute of Occupational Health, Helsinki.
Nygård C-H, Luopajärvi T, Cedercreutz G and Ilmarinen J (1987a): Musculoskeletal capacity of employees aged 44 to 58 years in physical, mental and mixed types of work. Eur J Appl Physiol Occup Med 56: 555–561.
Nygård C-H, Suurnäkki T, Landau K, Ilmarinen J (1987b): Musculoskeletal load of municipal employees aged 44 to 58 years in different occupational groups. Int Arch Occup Environ Health 59: 251–261.
Nygård C-H, Kilbom Å, Hjelm EW and Winkel J (1994): Life-time occupational exposure to heavy work and individual physical capacity. Int J Ind Ergon14: 365–372.
Nygård C-H; Huuhtanen P, Tuomi K and Martikainen R (1997): Perceived work changes between 1981 and 1992 among aging workers in Finland. Scand J Work Environ Health 23 (Suppl 1): 12–19.
Paterson DH, Cunningham DA, Koval JJ and St Croix CM (1999): Aerobic fitness in a population of independently living men and women aged 55–86 years. Med Sci Sports Exerc 31: 1813–1820.
Piers LS, Soares MJ, McCormack LN and O'dea K (1998): Is there evidence for an age-related reduction in metabolic rate? J Appl Physiol 85: 2196–2204.
Pimentel AE, Gentile CL, Tanaka H, Seals DR and Gates PE (2003): Greater rate of decline in maximal aerobic capacity with age in endurance-trained than in sedentary men. J Appl Physiol 94: 2406–2413.
Pohjonen T (2001): Perceived work ability of home care workers in relation to individual and work-related factors in different age groups. Occup Med 51: 209–217.
Pollock ML, Mengelkoch LJ, Graves JE, Lowenthal DT, Limacher MC, Foster C and Wilmore JH (1997): Twenty-year follow-up of aerobic power and body composition of older track athletes. J Appl Physiol 82: 1508–1516.
Proctor DN and Joyner MJ (1997): Skeletal muscle mass and the reduction of V_{O2max} in trained older subjects. J Appl Physiol 82: 1411–1415.
Rantanen T, Sipilä S and Suominen H (1993): Muscle strength and history of heavy manual work among elderly trained women and randomly chosen sample population. Eur J Appl Physiol Occup Physiol 66: 514-517.
Rantanen T, Era P and Heikkinen E (1997): Physical activity and the changes in maximal isometric strength in men and women from the age of 75 to 80 years. J Am Geriatr Soc 45: 1439–1445.
Rantanen T, Masaki K, Foley D, Ismirlian G, White L and Guralnik JM (1998): Grip strength changes over 27 yr in Japanese-American men. J Appl Physiol 85: 2047–2053.
Robertson A and Tracy CS (1998): Health and productivity of older workers. Scand J Work Environ Health 24: 85–97.
Rogers MA, Hagberg JM, Martin WW 3rd, Ehsani AA and Holloszy JO (1990): Decline in VO_{2max} with aging in master athletes and sedentary men. J Appl Physiol 68: 2195–2199.
Rohmert W and Landau K (1983): A new technique for job analysis. 1st edition. Taylor and Francis Ltd, London.
Roquelaure Y, Raimbeau G, Dano C, Martin Y-H, Pelier-Cady M-C, Mechali S, Benetti F, Mariel J, Fanello S and Penneau-Fontbonne D (2000): Occupational risk factors for radial tunnel syndrome in industrial workers. Scand J Work Environ Health 26: 507–513.
Rosen M, Sorkin JD, Goldberg AP, Hagberg JM and Katzel LI (1998): Predictors of age-associated decline in maximal aerobic capacity: a comparison of four statistical models: J Appl Physiol 84: 2163–2170.
Rutenfranz J, Seliger V, Andersen KL, Ilmarinen J, Flöring R, Rutenfranz M and Klimmer F (1977): Experiences with a cardiorecordersystem for continuous 24-hour registration of heart rate. [Erfahrungen mit einem transportablen Gerät zur kontinuerlichen Registrierung der Herzfrequenz für zeiten bis zu 24 Stunden] Eur J Appl Physiol Occup Physiol 36:171–185.
Sagiv M, Vogelaere PP, Soudry M and Ehrsam R (2000): Role of physical activity training in attenuation of height loss through aging. Gerontology 46: 266–270.
Samson MM, Meeuwsen IB, Crowe A, Dessens JA, Duursma SA and Verhaar HJ (2000): Relationships between physical performance measures, age, height and body weight in healthy adults. Age Ageing 29: 235–242.
Sandmark H, Wiktorin C, Hogstedt C, Klenell-Hatschek E-K and Vingård E (1999): Physical work load in physical education teachers. Appl Ergon 30: 435–442.

Saris WHM, Snel P, Baecke J, van Waesberghe F and Binkhorst RA (1977): A portable miniature solid-state heart rate recorder for monitoring daily physical activity. In: Biotelemetry 4, pp. 131–140. Ed. HP Kimmich, Base, Karger.

Schibye B, Hansen AF, Søgaard K and Christensen H (2001): Aerobic power and muscle strength among young and elderly workers with and without physically demanding work tasks. Appl Ergon 32: 425–431.

Shephard, R.J. (1984). Tests of maximal oxygen intake: a critical review. Sports Medicine, 2, 99–124.

Shephard RJ (1999): Age and Physical Work Capacity. Exp Aging Res 25: 331-43.

Shephard RJ (2000): Aging and productivity: some physiological issues. Int J Ind Ergon 25: 535–545.

Siegel AJ (1984): Exercise and aging. In: Sports Medicine, p. 279. Ed. RH Strauss, Saunders, Philadelphia.

Stamford BA (1988): Exercise and the elderly. Exercise Sport Science Rev 16: 341–379.

Stubbs NB, Fernandez JF and Glenn WM (1993): Normative data on joint ranges of motion of 25- to 54-year-old males. Int J Ind Ergon 12: 265–272.

Suurnäkki T, Nygård C-H, Ilmarinen J (1991): Stress and strain of elderly employees in municipal occupations. Scand J Work Environ Health 17 (Suppl 1): 30–39.

Sörensen L, Smolander J, Louhevaara V, Korhonen O and Oja P (2000): Physical activity, fitness and body composition of Finnish police officers: a 15-year follow-up study. Occup Med 50: 3–10.

Talbot LA, Metter EJ and Fleg JL (2000): Leisure-time physical activities and their relationship to cardiorespiratory fitness in healthy men and women 18–95 years old. Med Sci Sports Exerc 2: 417–425.

Tammelin T (2003): Physical acitivty from adolescence to adulthood and health-related fitness at age 31. Cross-sectional and longitudinal analyses of the Northern Finland birth cohort of 1966. URL http://herkules.oulu.fi/isbn9514272331.

Tanaka H, DeSouza CA, Jones PP, Stevenson ET, Davy KP and Seals DG (1997): Greater rate of decline in maximal aerobic capacity with age in physically active vs. sedentary healthy women. J Appl Physiol 83: 1947–1953.

Taylor J and Twomey L (1980): Sagittal and horizontal plane movements of the human lumbar vertebral column in cadavers and in the living. Rheum Rehab 19: 223–232.

Theorell T, Harms-Ringdahl K, Ahlberg-Hultén G and Westin B (1991): Psychosocial job factors and symptoms from locomotor system – a multicausal analysis. Scand J Rehabi Med 23: 165–173.

Torgén M and Kilbom Å (2000): Physical work load between 1970 and 1993 – did it change? Scand J Work Environ Health 26: 161–168.

Torgén M, Punnett L, Alfredsson L and Kilbom Å (1999a): Physical capacity in relation to present and past physical load at work: a study of 484 men and women aged 41 to 58 years. Am J Ind Med 36: 388–400.

Torgén M, Winkel J, Alfredsson L and Kilbom Å (1999b): Evaluation of questionnaire-based information on previous physical work loads. Scand J Work Environ Health 25: 246–254.

Tracy BL and Enoka RM (2002): Older adults are less steady during submaximal isometric contraction with the knee extensor muscles. J Appl Physiol 92: 1004–1012.

Trappe SW, Costill DL, Vukovich MD, Jones J and Melham T (1996): Aging among elite distance runners: a 22 year longitudinal study. J Appl Physiol 80: 285–290.

Troke M, Moore AP, Maillardet FJ, Hough A and Cheek E. (2001) A new comprehensive normative database of lumbar spine ranges of motion. Clin Rehabil 15: 371–379.

Trudeau F, Shephard RJ, Arsenault F and Laurencelle L (2001): Changes in adiposity and body mass index from late childhood to adult life in the Trois-Rivieres study. Am J Human Bilo 13: 349–355.

Viitanen JV, Heikkilä S, Kokko M-L and Kautiainen H (2000): Clinical assessment of spinal mobility measurements in ankylosing spondylitis: a compact set for follow-up and trials? Clin Rheumatol 19: 131–137.

Wilson TM and Tanaka H (2000): Meta-analysis of the age-associated decline in maximal aerobic capacity in men: relation to training status. Am J Physiol Heart Circ Physiol 278: H829–H834.

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