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Physical loads and aspects of physical performance in middle-aged men and women

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List of papers

This thesis is based on the following papers, which will be referred to by their Roman numerals.

I Torgén M, Alfredsson L, Köster M, Wiktorin C, Smith K, Kilbom Å. Reproducibility of a questionnaire for assessment of present and past physical activities. *Int Arch Occup Environ Health* 1997;70:107-118.

II Torgén M, Winkel J, Alfredsson L, Kilbom Å, Stockholm MUSIC I Study Group. Evaluation of questionnaire-based information on previous physical workloads. *Scand J Work Environ Health* 1999;25(3):246-254.

III Torgén M, Kilbom Å. Physical work load between 1970 and 1993 – did it change? *In press - Scand J Work Environ Health*.

IV Torgén M, Punnett L, Alfredsson L, Kilbom Å. 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* 1999;36(3):388-400.

V Torgén M, Swerup C. Factors related to sensory thresholds in a middle-aged population sample. *Submitted*.

List of abbreviations

BMI	Body mass index
BSA	Body surface area
CI	Confidence interval
CV %	Coefficient of variance
k_ω	Weighted Cohen's kappa correlation coefficient
LB score	Low back score
MC II	The second metacarpal bone
MT I	The first metatarsal bone
MUSIC	Musculoskeletal Intervention Center
N/S score	Neck/shoulder score
NYK	Nordic occupational classification code
P10, P50, P90	10th, 50th and 90th percentiles
P25-P75	Interquartile range
PIP III	Proximal interphalangial joint of the third finger
PPT	Pressure pain threshold
PR	Relative prevalence
PWL score	Physical work load score
QST	Quantitative sensory testing
REBUS	Rehabiliterings-Behovs-Undersökningen i Stockholms län
r_i	Intraclass correlation coefficient
RPE	Rate of perceived exertion
r_S	Spearman rank correlation coefficient
SEI	Socio-economic class
VAS	Visual analogue scale
VPT	Vibration perception threshold

Contents

Introduction

This doctoral work is a part of a multidisciplinary programme investigating the situation of elderly workers, the “Work After 45” programme, conducted at the National Institute for Working Life between 1991 and 1996 (Kilbom et al., 1998).

The background of the programme was the demographic situation in Sweden with an ageing population as in many other countries, both in Europe and in Asia. Work demands do not normally decrease with increasing age, despite a decrease in many aspects of work capacity, especially physical work capacity. Older employees therefore have to use more effort than younger ones to achieve the same level of performance. As a result, elderly workers often work at a level close to their maximal capacity, risking musculoskeletal injuries and health problems. This is true for dynamic jobs regarding use of large muscle groups, but in jobs involving predominantly small muscle groups decreased performance due to reduced age-related capacity is less obvious (Aminoff et al., 1996; Schibye et al., 1997). However, certain aspects of the working capacity, e.g. the ability to co-operate and make decisions improve with age, and together with large work experience, this makes the elderly very valuable at their work places (Aronsson et al., 1996).

One part of the “Work After 45” programme was the “REBUS” study, which formed the basis of this thesis and focused on physical loads during the last two decades, and different aspects of physical performance, in middle-aged men and women. The aim was to study physical loads at work, at present and in the past, in relation to physical performance. The majority of reported studies on working conditions are cross-sectional, and often consider only the present situation. However, conditions in the past may also influence present physical performance and health. Therefore, the quality of questionnaire data concerning physical loads in the past was also studied.

Impact of physical load

It is widely accepted that regular physical activity has positive effects on most body systems, e.g. on the body composition, metabolism, cardiorespiratory system, muscular strength and flexibility, and the immune system (Blair et al., 1992; Shephard, 1997). However, a negative relationship has been observed between physical activities at work and both musculoskeletal health (Bernard BP editor, 1997; Kilbom et al., 1996a; Kuorinka et al., 1990), and physical work capacity (Era, 1992; Nygård et al., 1987; Schibye & Christensen, 1997). In the cited studies workers in physically demanding jobs, e.g. cleaners, gardeners, and meat cutters, showed lower performance at tests of physical work capacity (e.g. isometric muscle strength, dynamic endurance, aerobic capacity) than those in less physically demanding jobs, and differences were found especially among the older workers. In young workers, the correlation between physical capacity and physical work-load seems to be positive (Era, 1992). Taken together these findings support a hypothesis that long-term physically demanding activities might have a lowering effect on physical capacity possibly in combination with effects of ageing. When this hypothesis is examined by comparing white- and blue-collar workers, differences in leisure-time physical exercise habits, life-style factors and general health must be taken into account (Ford et al., 1991; Rantanen et al., 1992). The combination of high physical workload and low physical training activities during leisure time might be of special importance. However, a negative influence of physically heavy loads on physical capacity and health has also been found in comparisons of workers performing the same kind of jobs at different work places and of groups doing similar work but with different ergonomic conditions at the same work place (Van der Beek et al., 1993). Thus there is some scientific reason to postulate that some occupational work activities have a long-term negative effect on physical capacity.

Several models have been reported showing pathways between work load and the individual. The model in Figure 1 is partly based on the conceptual model presented by Armstrong and co-workers (Armstrong et al., 1993), proposing additional pathways between the internal (inside the individual) and external variables. Physical/mental sensations and physical/mental performance are regarded as two partly independent reflectors of acute and long-term internal effects (Fig. 1). For example, alternations of physical and mental performance do not have to be accompanied by sensations, and vice versa. The central box in Figure 1 is meant to reflect the total human being, including characteristics such as age, skills, physical and mental status and gender.

The balance between work load and individual capacity defines the effects of load and thereby the possibility of remaining at work despite different individual limitations, like e.g. high age. Both sensations and performance are believed to be of importance in relation to “external effects”, and in modulations of external load in a continuous dynamic process (Estlander et al., 1998; Kilbom et al., 1996b) and can be assessed in many ways. Internal load and internal effects of load are more difficult to assess, but there are some possibilities, e.g. the percentage of maximal heart rate range (% HRR= $(HR_{work}–HR_{rest}) \cdot (HR_{max}–HR_{rest})^{-1} \cdot 100$) and the rate of perceived exertion (RPE) (Borg, 1970), of which RPE can also be assessed retrospectively. However, RPE is often considered unreliable in work physiology, as it is dependent on many factors besides basic physical dimensions. However, these other factors (e.g. muscle groups involved, temperature, time pressure, motivation etc.) are important modifiers of internal load and thereby of the external effects of work.

The studies in the thesis focus on different parts of the model described in Figure 1, i.e. studies I, II and III mainly deals with different aspects of the “external load box”, while studies IV and V focus more on the proposed connections between the boxes (arrows written in bold), and especially on the connections between the “external load box” and “physical performance box”.

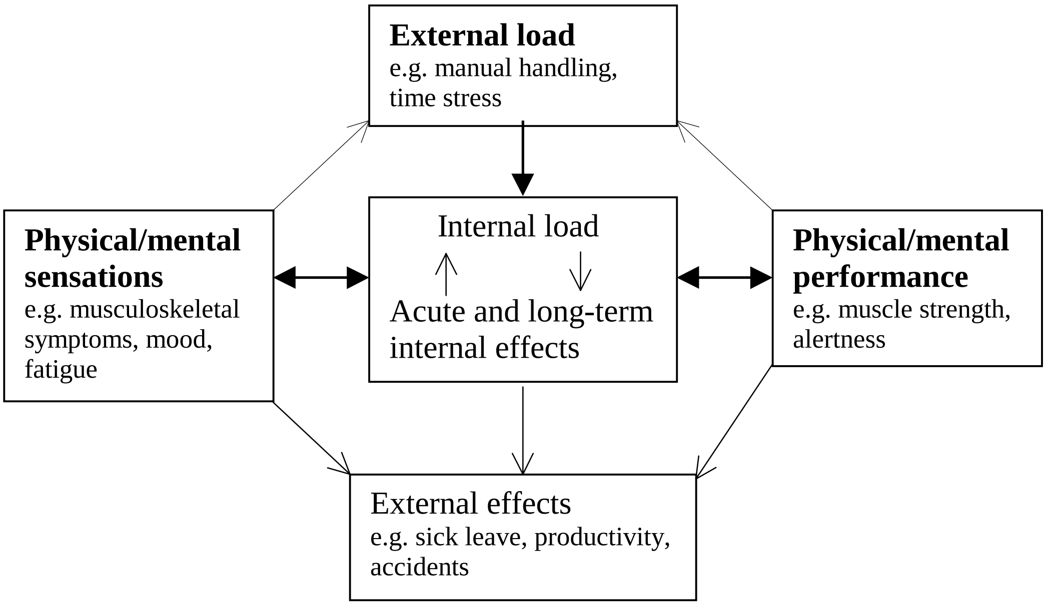


Figure 1. A model of some possible pathways of importance in musculoskeletal ergonomics. Arrows in bold represent the pathways studied in the present thesis.

Why assess physical load?

The impact on health by work is related to the balance between load and individual capacity, which is pivoted in the "stress-strain model" presented in the middle of the 1980s (Rohmert, 1984; Rutenfranz et al., 1990). In jobs where the worker can decide how to perform the work tasks, a balance between the load on the body and the physical capacity can be achieved even if the job, by its title, is categorised as physically demanding and the worker has certain limitations such as high age. In work settings of this kind strain is often found to below 40 % of the maximal capacity, which is the level of performance that can be maintained for a long time without accumulated fatigue (Åstrand, 1988). However, in many situations on and off work this optimal way of performing work does not exist, because of shortcomings in the work organisation and a lack of ergonomic knowledge and guidance. Altogether, physical load is believed to be of high importance in relation to different aspects of musculoskeletal health.

Physical load on and off work

Studies of physical work loads are often focused on manual handling, repetitive work with high demands for precision, and work with bent or twisted body postures. This is due to the frequent reports on negative influences of such work on the musculoskeletal system (Hughes et al., 1997; Luoma et al., 1998; Punnett, 1998; Punnett et al., 1991; Vingård et al., 1991a). In a recent Swedish population-based case-referent study a high physical energetic work load was also identified as a risk factor for low back problems in women, but not in men (Vingård et al., 1999). These results probably reflect a gender-divided labour market, but also possible gender differences in the effects of physical load on the lumbar region. On the other hand, epidemiological studies have indicated that leisure-time physical activities, i.e. hobby activities and physical training, have preventive effects on a number of diseases, including musculoskeletal problems (Blair et al., 1992; Helmrich, 1994; Kriska et al., 1988; Lemaitre et al., 1999), and is suggested as a possible way of delaying the ageing process and age-related functional limitation (Huang et al., 1998; Porter et al., 1995; Spirduso, 1980). Such leisure time activities differ in nature from those associated with musculoskeletal disorders and exert their effects by increasing the cardiovascular capacity and muscle mass. However, long-lasting vigorous sports activities have also been found to be associated to musculoskeletal problems (Vingård et al., 1998). But leisure time involves more than hobbies and sports activities, i.e. the so-called 'unpaid' or domestic work, which often is described as taxing (Hall, 1992; Lundberg, 1996), with parallels to adverse health effects seen in occupations dominated by similar tasks (Björkstén et al., 1996; Brulin et al., 1998). Domestic work is mostly discussed in relation to musculoskeletal problems among women. However, men also carry out a substantial amount of domestic work. Perhaps the negative health outcome seen predominantly in women is due to lack of exposure variation; that is, many women do similar work tasks during both working hours and leisure time, while men often carry out different tasks at work versus leisure time. Obviously there is a need to take both work- and non- work-related physical loads into account in epidemiological studies of musculoskeletal morbidity.

Assessment of physical load

Regional load

Accurate assessment of physical work loads are difficult to perform, as has been documented in recent review articles (Hagberg, 1992; Li et al., 1999). Methods for assessment of physical loads can be divided into three main categories, namely subjective assessments, observations and direct measurements, all with different advantages and shortcomings. Perhaps we would like to use an optimal set of measurement techniques in a big prospective cohort study in jobs with wide distributions of all important physical exposures and with no drop outs, and thereby create a "perfect" study. However, no such study will ever be performed, as the labour market is constantly changing and the working individuals are continuously trying to modify their way of performing the job in order to reduce the load and or increase productivity. Detailed measurements on specified work tasks might therefore be of limited help in explaining different effects of physical work load, e.g. musculoskeletal problems, on the population level. Unfortunately such problems are also difficult to handle in epidemiological studies, as they are fluctuating, in contrast to e.g. diseases such as cancer, which you either do or do not have.

In epidemiological studies of work-related musculoskeletal disorders, direct measurements or systematic observations at the work places are recommended in preference to questionnaire-based information (Kilbom, 1994; Van der Beek et al., 1998; Winkel et al., 1994). However, observation-based methods have also been criticised in favour of direct measurements, especially in evaluations of dynamic jobs (De Looze et al., 1994). Structured interviews (Wiktorin et al., 1999), or combinations of observations and interviews, e.g. a “Portable Ergonomic Observation” method (PEO) and “Arbeitswissenschaftliches Erhebungsverfahre zur Tätigkeitsanalyse” (AET) (Fransson-Hall et al., 1995; Romert et al., 1983), performed by skilled ergonomists, have been found to provide more reliable information on physical work loads than self-administered questionnaires. Check-lists are often efficient instruments for evaluation of single work places and for assessing the balance between work demands and the individual capacity, but are less usable in quantitative studies of relations between physical load and health outcomes (Kemmlert, 1995; McAtammy et al., 1993).

Job titles and the number of years spent in different jobs are widely used and can be combined with expert evaluations of physical exposure in these jobs, forming job-exposure matrices (De Zwart et al., 1997; Ilmarinen et al., 1991b; Vingård et al., 1992; Östlin, 1988). Self-reported information on physical work loads by questionnaires are frequently used, but the accuracy of these instruments are not always reported. The validity of some self-reports on gross activities describing the present work situation, e.g. the fraction of the working day spent sitting, has been reported as sufficient for use in epidemiological studies, while the validity of self-reports on body postures and manual material handling has been found to be lower (Viikari-Juntura et al., 1996; Wiktorin et al., 1993). However, some studies have shown acceptable validity for self-reports on hand/wrist exposures (Nordström et al., 1998), and on manual material handling and repetitive upper extremity work (Pope et al., 1998).

To summarise, the efficacy of a method is dependent on the context in which it is used and no single method can be recommended for general use, e.g. in epidemiological studies, individual risk estimation and laboratory studies.

Whole-body load

In studies on preventive effects of physical activity on morbidity and premature deaths, measurements of general physical load are widely used, also including leisure time activities and domestic work. However, physiological load in domestic work is often underestimated, probably leading to underestimation of effects of physical activity on health, especially in women (Andrew et al., 1998; Blair et al., 1993). In these studies the physical load is often measured in kilo-calories utilised per time unit, or in metabolic units (MET = the ratio of metabolic rate during activity to the metabolic rate at rest), but is seldom analysed in relation to effects on different parts of the musculoskeletal system (Ainsworth et al., 1993). This has been investigated in a recently published study on kitchen work, showing markedly higher physiological strain when relating work intensity to peak performance of the muscle groups involved, instead of relating it to maximal whole body performance (Aminoff et al., 1999). However, studies on general physical activity often pay great attention to the way in which valid information should be obtained on physical loads in the past (Chasan-Taber et al., 1996; Roeykens et al., 1998), and techniques for measurement of even life-long physical loads have been evaluated (Friedenreich et al., 1998). Those results indicates that in studies of musculoskeletal health in relation physical loads in the past, improvements might be achieved by adopting parts of some questionnaire and interview techniques used in general health research.

Loads in the past

Exposures that have occurred in the past are often no longer available for either observations or direct measurements. But impaired physical function and many chronic musculoskeletal disorders are believed to develop over a number of decades. Thus, in epidemiological studies of causality, and especially in case-control studies, questionnaires or questionnaire-based interviews are the method of choice, both because of their relatively low cost, and because the subjects can be asked to recall past exposures. The accuracy of self-reported information has been questioned for several reasons. One reason is the uncertainty as to whether and how the questions and the response alternatives have been understood, especially in self-administered questionnaires. But most of all, self-reports on historical events are questioned on the basis of presumed recall problems. The magnitude of memory difficulties is likely to be closely related to the kind of information requested; for example there may be major problems with details such as percentages of working hours with parts of the body in specified positions. It is also reasonable to presume that memory difficulties increase with time (i.e. more mistakes will be made when answering questions regarding workloads 25 years back in time compared to questions on workloads during the last year), and that the risk of differential misclassification of exposure due to symptom status may also increase with the length of the recall period. Few studies on the validity of physical work loads in the past have so far been published. But if the issue of recall problems concerning physical work exposures can be equalised with reports on general physical activities in the past, it can be said that acceptable data quallity has been found referring to information for ten years back in time (Blair et al., 1991) and even, in a recent study, to 20 and 30 years back in time (Falkner et al., 1999).

Aspects of physical performance

Measures of physical performance are meant to describe basic variables of importance for a satisfying work and leisure-time functioning. Studies of the structure of physical performance in relation to occupational work showed three main components; strength, endurance and movement quality (Hogan, 1991), and physical performance in terms of muscle capacity and aerobic power is believed to be of marked importance, especially in gender and age perspectives. If a job is regarded as physically demanding, aerobic power is often thought to set the limits for who is going to manage that job. Aerobic power therefore has a central role in the NIOSH guide for manual handling of loads in industrial work settings, with aims to avoid accumulated fatigue and risks for back injuries (NIOSH, 1981; Walters et al., 1993). However, on the basis of measurements of physical loads in demanding jobs, muscle strength has more often been found to set the limits than aerobic capacity (Jackson, 1994). Assessment of physical performance is useful for evaluation of the balance between physical work demands and the individual capacity, but there is no consensus as to whether decreased performance can act as a first sign of future musculoskeletal illness, or whether it just reflects ongoing or previous problems. To explore the true nature of physical performance, longitudinal studies are needed, and tests of physical performance have so far often failed to show that it has any predictive strength, for new cases of musculoskeletal disorders (Harju et al., 1991; Takala et al., 1998), except for an association observed between static back endurance and incident neck and low back disorders (Harju et al., 1991). Further, in a study of cervicobrachial disorders in the manufacturing industry low muscle strength was found to be associated with increased risks for future upper extremity disorders among individuals in traditionally heavy jobs, but not among those in jobs with a predominance of prolonged static load (Kilbom, 1988).

As musculoskeletal performance in a broader sense also depends on other capabilities than muscle strength and aerobic power, it is believed to be meaningful to include tests of e.g. balance and sensory thresholds, in assessments of physical performance.

Physical performance in relation to age

The decline in muscle strength with age is mainly related to changes in muscle composition, decreased muscle mass due to reduced physical activity, less efficient neurogenic motor control, and loss of motor neurones including muscle fibres (Aoyagi et al., 1992; Bemben et al., 1991; Frontera et al., 1991; Luff, 1998). In particular, a reduction of the muscle mass fraction of type II fast twitch fibres with age has been related to a decline in explosive and fast eccentric strength and to decreased control of postural sway (Hortobagyi et al., 1995; Izquierdo et al., 1999). The declined of strength with age is often most pronounced in the lower extremities and less so for hand grip (Engström et al., 1993), supporting the hypothesis of a relation to reduced physical activity level. These studies are often focused on assessment of maximal strength, while less is reported on development of muscle endurance in relation to age, i.e. time to exhaustion given a specified fraction of peak performance. However, the age-related endurance decline seems to be much less pronounced than the decline in maximal strength (Bemben, 1998; Laforest et al., 1990). Much of the age-related changes described above could theoretically be related to a decrease in physical activity with age and there are still doubts as to whether a primary age-dependent process within the muscle fibres also contributes to the observed reduction in muscle strength (McCarter, 1990).

The decline in aerobic power with age is mainly related to a reduced maximal heart rate and consequently a reduced maximal cardiac output (Åstrand et al., 1973). However, an increased body fat fraction and decreased physical activity with age also contribute (Jackson et al., 1995; Jackson et al., 1996).

Elevated sensory thresholds with age (e.g. perception thresholds and pain thresholds), especially on the distal part of the body, have been explained as a distal-proximal ageing process affecting all modalities of sensory function (Bartlett et al., 1998; Skov et al., 1998b). There are several possible reasons for theses age-related changes, ranging from a reduced number of peripheral receptors, demyelinisation of afferent nerve fibres, to a reduced capacity for central nervous processing.

Irrespective of the causes of the age-related decrease in physical performance, the maintenance of sufficient performance is important in relation to physical demands at work, since these may not decrease with age (Lusa et al., 1994; Miettinen et al., 1994). This is especially true in consideration of the demographic changes of today in most western countries, where an increasing proportion of middle-aged and elderly workers, many of them women, remain in unskilled but physically demanding occupations (WHO, 1993).

Physical performance in relation to gender

Gender aspects of physical performance have their relevance in light of the differences in body dimensions, body composition and hormonal regulation which results in differences in the impact of both internal (e.g. age) and external exposures (e.g. work loads).

The muscle strength in women is about 50 to 65 % of that in men, with the most marked difference in the upper extremity muscle groups (Heyward et al., 1986; Laubach, 1976). This difference is attributable to a smaller amount of lean body mass, smaller muscle fibre diameters, and a smaller amount of lean tissue in the upper part of the body in women (Frontera et al., 1991; Miller et al., 1993).

The total aerobic capacity in women is about 70 % of that in men, mainly as a result of differences in body size and thereby in the stroke volume and oxygen-transporting amount of haemoglobin, and to less lean body mass (Ogawa et al., 1992). However, physical fitness, i.e. the ability for body-weight-carrying performance, often calculated as maximal oxygen consumption per kilogram body weight ($mlO_2 \cdot min^{-1} \cdot kg^{-1}$) shows less difference (Engström et al., 1993; Nygård et al., 1994), and gender differences have to a large extent been found to relate to differences in the physical training status (Zwiren et al., 1983).

Gender differences in sensory thresholds are often reported, especially for pain thresholds. Several factors have been suggested as an explanation of these differences, e.g. speed of reaction, receptor density due to body size, sex-role expectation, nociceptive discrimination capacity, temporal summation and patterns of cerebral activation (Feine et al., 1991; Fillingim et al., 1998; Lautenbacher et al., 1991; Paulson et al., 1998; Stevens et al., 1998). But there are still doubts as to whether there are any basic gender differences in sensory perception.

Aims of the investigation

The overall aim of this investigation was to study physical loads in relation to physical performance among middle-aged men and women in a sample from the general Swedish population. Quality aspects of questionnaire data on physical loads in the past were also focused.

The specific aims were:

- To evaluate the reproducibility (intramethod reliability) of questionnaire-based information on present and past physical activities at work (papers I and II) and during leisure time (paper I).
- To evaluate the validity (intermethod reliability) of questionnaire-based information on past physical work loads (papers II and III).
- To examine the development in work loads/work careers during a quarter century period (1970-1993) in relation to calendar year, birth cohort and gender (paper III).
- To examine possible negative influences of long-lasting physical work loads on physical capacity (paper IV).
- To investigate individual and occupational factors possibly related to sensory thresholds (paper V).

Methods

Study groups

The thesis is based on two study groups, the first a follow-up of the REBUS study group which was established in 1970 (papers I, III, IV and V), and the second a follow-up of the Stockholm MUSIC-I study group, established in 1989 (paper II). The representativeness of the REBUS-93 study group was evaluated in relation to a Swedish population sample (Swedish 1990 census) (Statistics Sweden SCB, 1998) of corresponding age (15 934 men, 15 506 women).

The REBUS study (papers I, III, IV and V)

In 1970, a survey (the REBUS study - "Rehabiliterings-Behovs-Undersökningen i Stockholms län") was undertaken of 2,500 men and women representing the general population between the ages of 18 and 65 years and living in the county of Stockholm, except those living in the city of Stockholm. The purpose was to investigate the needs for medical, psychiatric and social services and to measure any discrepancies between actual needs and measures already taken to meet these needs (Bygren, 1974). The survey in 1970 included general medical examination, psychiatric examination including tests of personality and intelligence, tests of pulmonary function and aerobic power including ECG, examination of dental, visual and audiological status, occupational history, and social history.

In 1993, all subjects of the orginal REBUS survey without a musculoskeletal diagnosis in 1970 and below the age of 59 years in 1993 were identified and asked to participate in a re-examination, focusing on physical function and different aspects of musculoskeletal and mental health in relation to physical and psychosocial factors at work and during leisure time (the REBUS-93 study). Some subjects with serious mental and somatic diagnoses in 1970 were also excluded from the follow-up group, as they would presumably not have taken part in working life during the follow-up period between 1970 and 1993. Addresses in 1993 were obtained from national population registers. Approximately 62 % of the selected group, 232 men and 252 women, participated in the follow-up study, which was performed at the National Institute for Working Life in Solna between May 1993 and September 1994. The selection process between 1970 and 1993/94 is shown below (Table 1).

Paper I. This study was carried out on two sub-samples drawn from the 484 subjects in the REBUS-93 study. The first sub-sample, consisting of 44 consecutive subjects, answered the questionnaire a second time 2 weeks after participation in the study (group A). The second sub-sample, 123 consecutive subjects, answered the questionnaire a second time in 1994, i.e. 12 months after participation in the REBUS-93 study, regarding activities one year previously

Table 1. The selection process between the REBUS survey in 1970 and the follow-up in 1993.

Men	Women	Total	
1259	1320	2579	Participants in the REBUS survey in 1970
631	638	1269	Number of REBUS subjects below 59 years in 1993
62	42	104	Dead or lost in the registers (e.g. emigrated) between 1970 and 1993
69	50	119	Excluded due to musculoskeletal diagnosis in 1970
51	50	101	Excluded due to other serious diagnosis or social conditions in 1970
71	65	136	Excluded due to incomplete information in the 1970 survey
15	11	26	Excluded due to incomplete addresses in 1993 (incl. 4 recently dead)
363	420	783	Subjects asked to participate in the follow-up study in 1993
232	252	484	Participants in the follow-up study in 1993

(group B). None of the subjects was included in both sub-samples and all had to be gainfully employed when answering the questionnaire for the first time in the main study. Demographic descriptions of the subjects in the REBUS-93 study and in the two sub-samples, group A and group B, are presented in Table 2 and demographic information in relation to age groups, are presented in Table 3. In group A the reproducibility of information on both past and present physical activities was analysed and the calendar years 1970, 1975, 1980, 1985, 1990 and 1993 were chosen to represent the whole time period (1970 - 1993). In group B

Table 2. Gender, mean age, number of different occupations, percentage of the subjects who changed occupation during the follow-up period between 1970 and 1993, and percentage with low back symptoms during the last 12 months in the main REBUS study group and in two subgroups (A and B).

Variable		Main study men/women	Group A[1] men/women	Group B[2] men/women
Number of subjects		232/252	20/24	59/64
Mean age in 1993 (years)		49/48	50/49	47/47
No. of different occupations[3] in 1993		95/73	17/20	35/35
Subjects with more than one occupation between 1970 and 1993[3] (%)		59/63		
Gainfully employed in	1994 (%)			98/95
	1993 (%)	91/89	100/100	100/100
	1985 (%)	98/89	100/96	100/88
	1970 (%)	80/59	75/63	80/58
Low back symptoms[4] in	1993 (%)	52/53	55/67	46/44
	1994 (%)			54/44

[1] Subjects answering the same questions with a two-week interval during 1993
[2] Subjects answering the same questions with a one-year interval (1993 and 1994)
[3] According to the Nordic occupational classification, NYK (3-digit level)
[4] Any feeling of pain or discomfort during the last 12 months

Table 3. Characteristics of the subjects in the REBUS-93 study in relation to gender and age group (41-49 years, 50-58 years). Data are presented as mean values (M), standard deviations (SD).

	MEN				WOMEN			
	41-49 years n=148		50-58 years n=84		41-49 years n=170		50-58 years n=82	
Test	M	SD	M	SD	M	SD	M	SD
Age in 1993 (years)	46	2	54	3	46	2	53	3
Body height (cm)	179	6	178	7	166	5	164	5
Body weight (kg)	83	11	84	13	67	11	69	12
BMI ($kg \cdot m^{-2}$)	26	3	27	4	24	4	26	4
BSA (m^2)	2.0	0.1	2.0	0.2	1.7	0.1	1.7	0.1

possible influences of gender, age and low back health on the one-year reproducibility concerning work and leisure time physical activities in 1993 were analysed.

Papers III, IV and V. The whole REBUS-93 study group of 484 subjects was used in these studies.

The Stockholm MUSIC-I study (paper II)
The study group in paper II consisted of a subgroup of the Stockholm MUSIC-1 study subjects, originally selected in 1989. “MUSIC” is an abbreviation of *MUS*culoskeletal *I*ntervention *C*enter and is a network of ten departments in Stockholm with the aim of preventing musculoskeletal disorders (Hagberg et al., 1990). The subjects were selected from four subgroups (furniture removers, n=12; a sample from the general male population, n=27; medical secretaries, n=13; and a sample from the general female population, n=45) in order to cover a broad spectrum of physical work loads (Karlqvist et al., 1994). These subjects were all working in the Stockholm area during the Stockholm MUSIC-1 study, and most of them were still doing so in 1995, when they were contacted and asked to participate in a follow-up (paper II). Their addresses and phone numbers in 1995 were obtained from national population and registers and telephone directories. Approximately 82 % participated in the follow-up in 1995 (Table 4), and the main reasons for non-participation were: could not be located at a recent phone number or address; did not respond to phone calls and letters; refused to participate (two subjects).

Assessment of physical load

Assessment by questionnaire (papers I, II, III, IV and V)
All subjects in the REBUS follow-up study in 1993 were instructed to write down their occupational history at home for the time period between the initial REBUS survey in 1970 and 1993, comprising dates of entering and leaving each

Table 4 Participants (n=82) in the re-examination in 1995, and drop-outs (n=15). Employment status in and changes of occupations between 1989 and 1995 are given. The subjects are divided into four groups established in 1989 (furniture removers n=12, male population n=27, medical secretaries n=13, female population n=45).

	Male groups [1]		Female groups [2]		All (N) [3]
	Furniture Removers	Male population	Medical secretaries	Female population	
Subjects participating in 1995	8	23	11	40	82
Dropouts	4	4	2	5	15
Participants in 1995 (n=82)					
Gainfully employed	7	21	10	31	69
Subjects who changed occupation between 1989 and 1995	2	4	1	6	13
Unemployed	0	0	0	2	2
Old age pension	0	1	1	5	7

[1] Mean (range) age: furniture removers 46 (40-57) years; male population 47 (29-67) years.
[2] Mean (range) age: medical secretaries 54 (27-69) years; female population 51 (26-70) years.
[3] Mean (range) age: 50 (26-70) years.

occupation during that period, job titles, main job tasks, and working hours. On the examination day they filled in a self-administered questionnaire on work loads between 1970 and 1993, supported by their own occupational history notes. The questionnaire comprised 12 questions on different kinds of physical activities at work (papers I, III, IV and V), and in study I, 12 more items, with similar wording, concerning such activities during leisure time (Appendix A). The questions were supplemented by drawings illustrating the different kinds of physical activities asked about. Four additional items on physical training activities were also asked for and used in papers I, IV and V.

Four different response scales were used, a semi-continuous scale (Borg, 1970), a visual analogue scale (VAS), and two ordinal scales (Appendix C). Physical activities during each occupation of at least 12 months were recorded. Long-term work in the same occupation was divided into 5-year periods and the questions were answered once for each period, starting with the present work in 1993. Thus each work-load question could be answered a maximum of 24 times, if the subject had changed to a new occupation each year during the time period between 1970 and 1993. Questions were asked about the same kinds of physical activities during leisure time, but in this case a response was required for every fixed fifth year, (i.e. 1970, 1975, 1980, 1985 and 1990), starting with the current leisure time in 1993, and concerned all seven days of the week.

In study I, the group A retest questionnaire (two-week reproducibility) contained exactly the same questions as the questionnaire in the main study, in contrast to the group B retest questionnaire (one-year reproducibility), which was modified to contain questions only about the physical activities at work and during leisure time in 1993. The retest questionnaires in paper I were distributed only once to the subjects, in order to maintain the selected time interval between the main study and the retest.

In study II, questionnaire information on historical physical work loads was validated by comparing self-reports (collected in 1995) on physical workloads six years previously (in 1989) with worksite measurements obtained in 1989, which were used as criterion values. Reports on perceived general exertion were validated by heart rate measurements. In 1989 illustrated questions about work postures and manual handling were used (Appendix B). Their reproducibility for current work loads has previously been evaluated by a test-retest procedure in a population study of 343 subjects (Wiktorin et al., 1996) and validated in relation to worksite measurements comprising the same subjects as in study II (Wiktorin et al., 1993). Physical activities described by these items were quantified as a proportion of the working day, or as the frequency per hour (Appendix C). In 1995 some of the items used in the REBUS-93 study (Appendix B) were added to the items described above, in order to investigate the influence of different response scales on the validity.

In order to find a physical work-load factor suitable for both men and women, that was stable between 1970 and 1993, and to reduce the number of work load variables, a factor analysis was performed on six questions concerning activities at work involving whole body load, described in Appendix A (sitting, hands high, forward bending, bent/twisted body postures, and two items on lifting). In order to standardise the variables for this procedure, the proportion of the work day spent sitting was inverted to indicate time standing or walking and the VAS (0-100 mm) scale was converted to a five-degree ordinal scale (0-20 mm=5, >20-40 mm=4 etc.). Initial factor analysis for work activities was performed on the 1993 data. For each gender, all six variables fitted into one factor, a "physically demanding work" dimension with acceptable variable loading (above 0.4) for most variables. The factor analyses were repeated for 1983 and 1973, and the initial factor solution was found to be reasonably stable over time (Kaiser Measure of Sampling Adequacy, 0.62-0.82). Thirty-two of 36 individual variable loadings (six variables for each year and gender) exceeded 0.40: among men they averaged 0.70 (range 0.51-0.84), and among women 0.54 (range 0.23-0.81). The factor solution was cross-validated by randomly allocating the men and women of the study group to one of two groups (large group: 135 men and 123 women; small group: 75 men and 101 women) and comparing the principal factor solution in the small group with the factor solution in the large group. Only minor differences were found between these groups. A physical work load score (PWL) score was calculated as the sum of the single year values of all six variables in the factor, resulting in one PWL score for each subject and calendar year from 1970 to 1993. The remaining six items (use of visual display terminal, whole body vibrations, hand vibrations, precision work, repetitive work and perceived general exertion) were treated as separate variables.

In study IV the average annual PWL scores were calculated for different time periods as follows: 5-year period 1989-1993; 10-year period 1984-1993; 15-year period 1979-1993; 20-year period 1974-1993. Missing values, for years when subjects were not employed, were treated as zeros (0) in the calculation of the PWL scores. Finally, the PWL scores for different time periods were divided into tertiles (low, intermediate and high) according to the distribution of the PWL scores, separately for each gender.

Assessment by work-place measurements (paper II)

Physical work loads were recorded individually at the work places during a normal working day for each of the 97 subjects in 1989, and used for validation of self-reported work loads in study II. The heart rate was recorded during a whole working day by the Sport Tester PE 3000 (Polar Electro, Finland) and the percentage of time spent sitting was determined with the Posimeter device (Selin et al., 1994). Body postures, repetitive finger/hand movements and manual handling were recorded by experienced ergonomists and physiotherapists with the PEO method (Fransson-Hall et al., 1995). The heart rates and the PEO results of the observation day were weighted for a ”typical working week” based on interview information on task durations during the week (Fransson-Hall et al., 1995; Karlqvist et al., 1994).

Assessment by expert evaluation (paper III)

Almost all job titles in the Nordic Occupational Classification system (NYK “Nordisk Yrkesklassifikation” codes at the 3-digit level (International Labor Office, 1958), have been scored by an expert panel for possibly harmful physical work loads on different body regions (low back, neck/shoulder, hip and knee).The panel consisted of four professionals on ergonomics (two physicians, one physiotherapist, and one occupational health nurse), making judgements based on their own experience on each occupation without knowledge of the results from the other three members of the panel. A four-level ordinal scale was used (1=low load, 2=rather low load, 3=rather high load and 4=high load). The scores for different body parts and occupations were calculated as the mean of the scores given by members of the panel (Vingård et al., 1992). The expert matrix scores on low back (LB) and neck/shoulder (N/S) loads were used in study III.

Assessment of physical performance

Isometric strength (papers IV and V)

Maximal trunk extension and trunk flexion strength were measured in a standing position using calibrated strain gauges (Asmussen et al., 1961), and with the proximal supporting point at the upper level of the iliac crest and the most distal point at the top of the axilla. Maximal isometric right hand grip and right knee extension strength were measured in a sitting position with elbow and knee flexion angles of 90° (Kilbom et al., 1981) and with a distal supporting point at the malleolus level for the knee extension strength test. The individual result of each test was the highest value of the first two correctly performed trials that showed a maximal difference of 10 per cent.

Isometric strength in Newtons (N), are correlated to anthropometric measures and especially to estimated body surface area (BSA) (Du Bois et al., 1916) and each individual strength result was therefore divided by the calculated BSA value (m^{-2}), and finally dichotomised at the 25th percentile level, relative to the distribution for each gender, for use in the multivariate analyses in study IV. An average isometric strength variable related to BSA was also calculated on the basis of the trunk flexion, trunk extension, hand grip, and leg extension strength results, and used for multivariate analyses in study V.

Dynamic endurance (paper IV)

Curl-ups, squatting and weight-lifting were chosen as tests of dynamic endurance, as they are considered safe and are easy to perform irrespective of fitness level. The tests were paced at 60 movements per minute by a metronome. The curl-up test was performed with the subject lying down on a bench with the arms crossed on the chest and the legs supported with 90 degree flexion in both hip and knee joints. The trunk was raised until the scapula was free from the bench surface (Bergkvist et al., 1992). In the squatting test the subject stood on the floor with the hands held at the waist and squatted down below the 90-degree level in the knee joints. In the weight-lifting test the subject stood on the floor with a weight in each hand (10 kg for men and 5 kg for women) and performed alternating lifts with the right and left arm, elevating the weights from the shoulder level to the straight arm position (Alaranta et al., 1994; Alaranta et al., 1990). Endurance was measured as the number of curl-ups, squattings or weight lifts performed up to exhaustion or to a maximum of 50 repetitions (whichever occurred first). Individual values of dynamic endurance were finally dichotomised at the 25th percentile level, relative to the distribution for each gender, for use in the multivariate analyses.

Aerobic power (papers IV and V)

The maximal aerobic power was estimated from the heart rate and work load in a submaximal ergometer test on an electrically braked bicycle (Siemens-Elema, Germany) with a pedalling rate of between 55 and 65 revolutions per minute. An electrocardiogram (ECG) was recorded continuously and the heart rate was measured from the ECG recordings. The maximal oxygen consumption ($l \cdot min^{-1}$) was estimated from the heart rate measured during the fifth and sixth minutes of submaximal work loads according to the nomogram of Åstrand and Ryhming (Åstrand et al., 1954) and corrected for age according to Åstrand (Åstrand, 1960). The mean of estimations at two submaximal work loads with heart rates exceeding 120 beats per minute was used. Physical fitness was expressed as maximal oxygen consumption per minute and kilogram body weight. Individual values of physical fitness were finally dichotomised at the 25th percentile level, relative to the distribution for each gender, for use in the multivariate analyses in study IV.

Sensory thresholds (paper V)

Pressure pain thresholds (PPT) were measured with a pressure algometer (Somedic Sales AB, Hörby, Sweden), a previously evaluated method (Jensen, 1990). The pressure was applied perpendicular to the skin surface with a 1.0 cm^2 circular aluminium tip with rounded edges, and was increased by 25 kPa per second. The subject was asked to press a button, and thereby end the pressure rise, when the sensation of pressure changed to pain. PPT was measured in a seated position at four locations, once at each location, on the right side of the body (the thenar area, the palmar aspect of the proximal interphalangeal joint (PIP) of the middle finger, the upper trapezius muscle half-way between C7 and the acromion, and the anterior surface of the bony area of the tibia half-way between the knee and ankle).

Vibration perception thresholds (VPT) were measured by a hand-held device producing 100 Hz sine wave vibrations, and the amplitude in micrometers of a plastic cylinder held perpendicular to the skin surface was read from a digital display (Vibrameter[R], Somedic Sales AB, Hörby, Sweden) (Goldberg et al., 1979). The application force was kept constant at a level corresponding to the weight of the hand-held device (0.55 kg) by a digital indication on the instrument. The "method of limits" was used, i.e. the level first perceived by the subject when the stimulus was increased from zero was defined as the vibration perception threshold. The subject was asked to say "now" when the first sensation of vibration was felt and the threshold was calculated as the average of four consecutive measurements. Vibration thresholds were measured with the subject lying down, at two locations on the right side of the body, namely the middle of the dorsal surface of the second metacarpal bone (MC II) and the first metatarsal bone (MT I).

Thermal perception thresholds for cold, warmth, and heat pain were measured using a computerized thermostimulator with a thermode size of 12.5 cm^2 (Thermotest[R], Somedic Sales AB, Hörby, Sweden). The thresholds were determined according to the "method of limits", starting from a baseline temperature in the neutral region of 32 ^oC (Swerup et al., 1987; Verdugo et al., 1992), and the thresholds were calculated as the absolute difference from 32 ^oC. Difference (warm/cold) perception thresholds were calculated as the algebraic sum of the thresholds for cold and warmth. For the tests of cold and warm thresholds the subject was asked to press the button of a hand-held switch, thereby terminating the stimulus, at the first sensation of cold or warmth. Eight cold stimuli were followed by eight warm stimuli (randomized interstimulus interval 4-10 s, stimulus rate $1^oC \cdot s^{-1}$), and the mean value of the thresholds were calculated after exclusion of extreme values. For measurement of the heat pain threshold five warm stimuli were given (randomized interstimulus interval 4-10 s, stimulus rate $2\ ^oC \cdot s^{-1}$), and the subject was asked to press the button when the sensation of heat changed to pain. The heat pain threshold was calculated as the mean of stimuli 2-5. All three types of tests were performed on the thenar eminence of the right hand, and cold and warm thresholds were determined on the lateral surface of the right foot slightly in front of and below the lateral malleolus. The subjects were lying down and the skin temperature at the measurement points was measured with a digital device (Craftemp[R], Astra Tech AB, Mölndal, Sweden), before testing.

Statistics

All statistical analyses were performed with the SAS program (SAS Institute, 1985), except for calculations of kappa coefficients (Bodin L, Örebro personal communications).

Paper I
The 10th, 50th and 90th percentiles (P10, P50, P90) were used to describe the distribution of responses to all physical activity questions. The two-week and one-year reproducibility of the physical activity responses was analysed by intraclass correlation coefficients (r_i). These coefficients were calculated by the one-way ANOVA procedure (Armstrong et al., 1992; Fleiss et al., 1973) .

Paper II
The distribution of questionnaire responses was summarised using mean (M) values, ranges, and tenth, fiftieth and ninetieth percentiles.

The six-year reproducibility of the questionnaire items was analysed with weighted Cohen's kappa coefficients (k_ω) with 95 % confidence intervals (CI). Kappa coefficients describe agreement beyond chance and produce results identical to those of intraclass correlation coefficients, if calculated with quadratic weights on categorical responses. Kappa values exceeding 0.75 were regarded as 'excellent agreement' beyond chance, values below 0.40 as 'poor agreement' and values between 0.40 and 0.75 as 'fair to good agreement' (Fleiss, 1981)**.**

Validity was analysed for the retrospective questionnaire responses obtained in 1995, using work site measurements performed in 1989 as reference values. The response scales differed between the measurements at the workplaces in 1989 and the questionnaire items in 1995 so that exact matching of scales was not possible, and the Spearman rank correlation coefficient (r_s) was chosen for calculation of agreement. A correlation coefficient of at least 0.6 was regarded as an indicator of high agreement.

Paper III
For descriptions of variables, mean values, standard deviations (SD) and percentiles (P10, P50, P90) were used. The distribution of work-load variables in the study was related to:

- Gender - men, women.
- Birth cohort - born 1935-39, 1940-44, 1945-49, 1950-52.
- Age - 20, 25, 30, 35, 40, 45, 50, 55 years.

- Occupational class (NYK class) - professional work, health/social work, administrative work, sales work, agricultural work, mining, transport work, production work, service work.
- Socio-economic class (SEI class) - blue-collar workers (including farmers), white-collar workers, self-employed, and not employed.

The variation of work loads during the follow-up period was expressed as coefficient of variance (CV %) for PWL, LB and N/S scores, and calculated as SD in per cent of M, based on all non-missing annual values.

Paper IV

The distribution of age and body dimensions was described with mean values, and standard deviations. Physical capacity results were described with mean values, standard deviations, and interquartile range (P25-P75). Pearson's correlation coefficients (r_p) were calculated between isometric muscle strength results and different anthropometric parameters, in order to evaluate the effect of body size on muscle strength and thereby to find out what variables to be used in the multivariate analyses.

Personal factors such as age, physical training habits, smoking habits and musculoskeletal symptoms were regarded as potential effect modifiers or confounders of the relation between physical work load and physical capacity. They were dichotomised as follows:

- age class: subjects between 41 and 49 years or between 50 and 58 years in 1993.
- training class: at least one, or less than one regular high- or medium-intensity training session per week in 1993.
- smoking class: smoking in 1993 (including party smokers) or not.
- symptom class: any kind of musculoskeletal symptom during the last week in the body parts involved in each test, or no such symptoms.

Effect modification was analysed by construction of interaction terms consisting of the exposure variable and each effect modifier (three levels of PWL scores in combination with two classes of age, training, smoking, or symptoms respectively). High age (50 years or more), lack of physical training, smoking and musculoskeletal symptoms were related to varying degrees to level of physical exposure, were therefore regarded as possible confounders and kept in the final regression models, except in the analyses of aerobic power, where age was not in the model because it was already adjusted for in calculation of the individual values.

The relationship between physical work load and physical capacity was studied by calculating the relative prevalence (PR) of low capacity (the lowest quartile), comparing those with a medium or high physical work load with those exposed to a low physical work load. Adjusted PR with 95 % CI was calculated by means of a log-binomial model using the SAS software GENMOD procedure with logarithmic link function and a binomial distribution (Armstrong et al., 1992; Skov et al., 1998a; Thompson et al., 1998), where the concomitant influences of confounding factors were taken into consideration. All multivariate analyses were made separately for men and women, and separately for each kind of capacity and time period (1993, 1989-1993, 1984-1993, 1979-1993, 1974-1993).

The primary hypothesis was that high physical work load was associated with decreased physical capacity. If the opposite was seen, an alternative hypothesis of possible strengthening effects of high physical work load was tested in additional post hoc analyses, by dichotomising the capacity results at the 75th percentile level.

Paper V

The distributions of variables are described by the mean value, standard deviation, and interquartile ranges. Student's *t*-test was used for evaluation of differences in variables between men and women. Because of the skew distribution of vibration thresholds, these values were transformed to logarithms which brought the data to a more Gaussian shape. Standard deviations in logarithmic units were then used to calculate upper and lower limits, after which standard deviations in original units were computed (Dorfman et al., 1997).

Multivariate analyses of covariation were performed separately for each gender by fitting a multiple linear model using the SAS software REG procedure (SAS Institute, Inc., Cary, NC, USA), separately for each sensory threshold in relation to independent variables. Variables were chosen with the aim of exploring sensory thresholds in relation to both individual factors and some aspects of physical work load, using one model for all sensory thresholds. Individual factors of known importance in relation to peripheral sensory function are age, skin temperature, and body height (the latter as an indicator of nerve fibre length). Besides these variables, some others were also believed to be of interest in relation to sensory function, e.g. body weight, BMI, BSA, tobacco smoking, ethanol consumption, exposure to occupational solvents and vibration, musculoskeletal symptoms, and different measures of physical capacity. Rank correlation coefficients (r_s) between possible independent variables were calculated, in order to extract an optimal number of uncorrelated variables for the multivariate model. Eight independent variables were finally selected: age, body height, skin temperature, dummy variables for smoking in 1993 and musculoskeletal symptoms during the last week before examination, a muscle strength index, calculated maximal oxygen consumption capacity, and average PWL score for the last 15 years (1979-1993). Results from the multivariate analyses are presented as parameter estimates with level of significance (p value) for each independent variable in the model. The parameter estimate of an independent variable defines the change in the dependent variable (sensory threshold) per each step of change in the independent variable, corrected for influence of all other independent variables in the model.

Results

Representativeness of the REBUS-93 study group

The representativeness of the REBUS-93 study group in relation to a Swedish population sample (Swedish 1990 census) of corresponding age (15 934 men, 15 506 women) is shown in Table 5.

There was a higher percentage of white-collar and a lower percentage of blue-collar workers in the study group and the percentage of unemployed was lower in the REBUS-93 study group than in relation to the Swedish population sample (Tab. 5).

Comparison of distributions of occupational classes (NYK) between the women in the REBUS-93 study group and the women in the whole Swedish population showed higher percentages in professional/technical and administrative work in the REBUS group. Among the men in the REBUS-93 study there were higher percentages in professional/technical work and sales work, and lower percentage in production work compared to the men in the whole Swedish population.

The male drop-outs in the REBUS-93 study (n=131) showed the same age distribution as the male participants among the men (mean age 49 years in both groups), in contrast to a slightly higher age among the female drop-outs (n=168) (mean age: participants 48 years, drop-outs 49 years). The distribution of occupational classes among the drop-outs was similar to that of the participants except for a lower percentage in professional work (participants: 28 % in men and 19 % in women; drop-outs: 19 % in men and 8 % in women) and a higher percentage with no occupation (participants: 6 % in both men and women; drop-outs: 15 % in women and 18 % in men).

Table 5. Distribution of socio-economic classes in relation to occupational class (NYK) in subjects in the REBUS-93 study (232 men, 252 women), and in the Swedish population (Swedish 1990 census) of corresponding age (between brackets). All figures refers to the situation in 1990 calculated as percentage of the total number of subjects. Statistically significant differences in proportions between the study group and the Swedish population has are indicated (*).

NYK class[1]	White-collar workers	Blue-collar workers	Self-employed	Total
WOMEN				
0- professional	18.7(13.4)*	0.0(0.2)	0.4(0.3)	19 (14)*
1- health	6.8(8.5)	13.5(14.8)	0.4(0.4)	21 (24)
2- administrative	27.4(20.1)*	0.0(0.0)	0.4(0.4)	28 (20)*
3- sales work	4.0(1.6)	1.6(3.7)*	1.2(1.0)	7 (6)
4- agricultural	0.0(0.0)	0.8(1.2)	0.0(0.0)	1 (1)
5- mining	-- (--)	-- (--)	-- (--)	-- (--)
6- transport	2.0(1.3)	1.6(1.4)	0.4(0.1)	4 (3)
7+8- production	0.8(0.2)	1.6(5.4)*	0.8(0.2)	3 (6)*
9- service	1.2(0.8)	5.6(8.3)	0.0(0.8)*	7 (10)*
Not employed	--	--	--	5 (12)*
Missing	--	--	--	5 (4)
All	61 (46)*	25 (35)*	4 (3)	100 (100)
MEN				
0- professional	26.7(17.5)*	0.9(0.3)	0.4(0.7)	28 (18)*
1- health	0.9(2.4)*	0.0(0.7)*	0.0(0.2)*	1 (3)*
2- administrative	14.2(10.5)	0.0(0.0)	0.4(0.3)	15 (11)
3- sales work	10.8(5.2)*	0.4(0.6)	1.7(1.7)	13 (8)*
4- agricultural	0.4(0.3)	0.0(3.3)*	0.0(0.3)*	0 (4)*
5- mining	-- (0.0)	-- (0.3)	-- (0.0)	-- (0)
6- transport	1.3(1.4)	4.5(4.4)	0.4(0.9)	7 (7)
7+8- production	0.0(1.0)*	18.1(25.5)*	2.6(2.7)	21 (29)*
9- service	1.3(2.4)	0.9(2.8)*	0.0(0.5)*	2 (6)*
Not employed	--	--	--	5 (9)*
Missing	--	--	--	8 (5)*
All	56 (41)*	25 (38)*	6 (7)	100 (100)

[1] 0=Professional, technical and related work. 1=Health and nursing work, social work. 2=Administrative, managerial and clerical work. 3=Sales work. 4=Agricultural, forestry and fishing work. 5=Mining, quarrying and petroleum extraction work. 6=Transport and communication work. 7+8=Production work 9=Service work.

Reproducibility of self-reported physical loads (papers I, II)

Test-retest reproducibility

The two-week reproducibility varied according to the kind of physical activity, and to the time chosen during the follow-up period. No distinct time trend over three chosen years (1975, 1985, 1993) was observed, except for the questions about VDT work, bent or twisted body postures and handling of loads exceeding 15 kg, which showed lower reliability for distant years (Table 6). Thus the test-retest reliability showed no overall tendency to deteriorate concerning different physical activities in the past. The test-retest reproducibility for activities at work generally exceeded that for leisure time activities, except for precision work and hands below knee level (Table 6). The highest test-retest results for activities at work were obtained for whole body vibrations (r_i 1.0) and handling of loads between 5 and 15 kg (r_i 0.8), and the lowest for precision work (r_i 0.4) and hands below knee level (r_i 0.6). The highest test-retest reproducibility for leisure-time activities was noted for hand vibrations (r_i 0.7) and repetitive movements (r_i 0.7), and the lowest for bent or twisted body postures (r_i 0.4) and whole body vibrations (r_i 0.5).

The test-retest reproducibility for different kinds of physical training was lower than that for activities at work (Tables 6 and 7).

Reproducibility regarding physical loads in the past

The one-year reproducibility exceeded the test-retest reproducibility (two-week) results regarding five of the 12 questions on physical activities at work (perceived exertion, sitting, use of VDTs, precision work, hands below knee level), but this finding might have been due partly to the wider distribution of responses in the one-year group. For leisure-time and training activities only the item on precision work showed higher one-year reproducibility.

The six-year reproducibility (k_ω) of different questionnaire items varied, with the highest values for the proportion of the working day spent sitting (k_ω 0.9) and perceived general exertion (k_ω 0.7) and the lowest values for forward bending of the trunk (k_ω 0.4) and head bent forward (k_ω 0.4). When the six-year reproducibility results from one study group (n=87) were compared with the one-year reproducibility results from another study group (n=123), using similar questionnaire items, no significant differences were found (Table 8).

Influence of gender and musculoskeletal health

No consistent differences between genders were found either for one-year or six-year reproducibility (Table 8). Regarding the one-year reproducibility for physical work loads, the largest differences were noted for whole body vibrations (men r_i 0.82, women -0.02), and hands above shoulder level (men r_i 0.84, women 0.25), and regarding the six-year reproducibility, for the items on perceived exertion (men k_ω 0.81, women 0.51), and lifting of loads between 1 and 5 kilograms (men k_ω 0.68, women 0.19). Higher reproducibility in women than in men was more

Table 6. Self-reported physical activities at work and during leisure time on three different occasions (1975, 1985 and 1993) described by the 50th, and 90th percentiles (P_{50}, P_{90}) and reproducibility calculated as intraclass correlation coefficients (r_i) in subjects answering the same questions twice with a two-week interval. The percentiles are calculated as the median value of both test and retest. (n=44)

Questions[1]	year	Work P_{50}	Work P_{90}	Work r_i	Leisure time P_{50}	Leisure time P_{90}	Leisure time r_i
Perceived exertion	-93	11	13	0.67	11	13	0.64
(6-20)	-85	11	15	0.80	11	15	0.44
	-75	11	14	0.78	11	15	0.52
Sitting	-93	62	95	0.64	36	78	0.65
(% of the time)	-85	61	93	0.57	30	67	0.51
	-75	39	89	0.68	26	67	0.41
VDT use	-93	11	91	0.93	2	18	0.55
(% of the time)	-85	3	49	0.81	0	8	0.73
	-75	1	30	0.79	0	5	0.14
Whole body vibrations	-93	1	9	0.95	7	28	0.43
(% of the time)	-85	1	9	0.99	7	37	0.54
	-75	0	23	0.97	10	44	0.48
Hand vibrations	-93	1	14	0.85	3	14	0.71
(% of the time)	-85	0	26	0.77	2	13	0.68
	-75	1	33	0.80	3	15	0.65
Precision work	-93	1	1	0.36	1	4	0.60
(1-5)	-85	1	1	0.36	1	4	0.61
	-75	1	1	0.39	2	4	0.54
Hands above shoulders	-93	1	4	0.75	1	3	0.56
(1-5)	-85	1	5	0.76	1	3	0.54
	-75	1	5	0.83	1	3	0.64
Hands below knees	-93	1	4	0.61	2	4	0.55
(1-5)	-85	1	4	0.58	2	4	0.60
	-75	1	4	0.62	2	5	0.79
Bent or twisted body	-93	1	5	0.74	1	4	0.41
(1-5)	-85	1	5	0.67	1	3	0.40
	-75	1	5	0.55	1	5	0.50
Repetitive movements	-93	2	5	0.64	1	4	0.75
(1-5)	-85	1	5	0.72	1	5	0.65
	-75	1	5	0.64	2	4	0.67
Loads from 5 to 15 kg	-93	1	5	0.89	2	4	0.50
(1-5)	-85	2	5	0.85	3	5	0.68
	-75	2	5	0.86	3	5	0.64
Loads exceeding 15 kg	-93	1	4	0.83	1	3	0.67
(1-5)	-85	1	5	0.84	1	4	0.67
	-75	1	5	0.67	1	4	0.47

[1] The questions are briefly described in Appendix 1A.

Table 7. Self-reported physical training activities during three different years (1975, 1985, and 1993) in subjects answering the same questions twice in 1993 with a two-week interval. The distribution is described by the 50th and 90th percentiles (P50, P90) and reproducibility is calculated as intraclass correlation coefficients (ri). The percentiles are calculated as the median value of the percentiles from both test and retest. (n=44)

Questions[1]	year	P_{50}	P_{90}	r_i
High-intensity training	-93	1	3	0.51
(1-4)	-85	2	3	0.75
	-75	2	3	0.61
Medium-intensity training	-93	2	3	0.72
(1-4)	-85	2	4	0.53
	-75	2	3	0.58
Low-intensity training	-93	2	4	0.56
(1-4)	-85	2	4	0.32
	-75	2	4	0.30
Strength training	-93	1	1	1.00
(1-4)	-85	1	2	0.18
	-75	1	1	0.91

[1] The questions are briefly described in Appendix 1A.

frequent in the six-year reproducibility group than in the one-year group, and was most pronounced for the items on repetitive finger movements (men k_ω 0.07, women 0.78) and head rotation (men k_ω 0.37, women 0.66).

Higher reproducibility in subjects with low back symptoms during the last year compared with those without symptoms was found for eight of the 12 questions on physical activities at work in the one-year reproducibility study, for nine of the 16 questions on leisure-time activities and training, and for seven of the 13 items on work loads in the six-year reproducibility study. The largest differences between the two low back health groups were seen in the one-year reproducibility study for hands above shoulder level at work (with symptoms r_i 0.94, without symptoms 0.64), and occupational precision work (with symptoms r_i 0.82, without symptoms 0.56). The influence of neck/shoulder symptoms on reproducibility was also examined, with similar results.

Table 8. Self-reported physical activities at work and during leisure time among 123 subjects (the REBUS-93 study: 59 male, 64 female) answering the same questions about 1993 activities both in 1993 and one year later in 1994 (one-year recall). Another study group with 87 subjects (the MUSIC study: 39 male, 58 female) answered items twice with a six year interval, in 1989 and in 1995 (six-year recall). Reproducibility is analysed by intraclass correlation coefficients (r_i) and weighted kappa coefficients (k_ω).

			One-year recall			Six-year recall
			Work	Leisure time		Work
Questions [1]		Scale	r_i	r_i	Scale	k_ω
Perceived exertion	-all	(6-20)	0.76	0.46	(0-14)	0.70
	-men		0.79	0.42		0.81
	-women		0.72	0.50		0.51
Sitting	-all	(% of time)	0.69	0.40	(1-6)	0.86
	-men		0.65	0.30		0.85
	-women		0.95	0.22		0.86
Hands above shoulders	-all	(1-5)	0.55	0.29	(1-6)	0.45
	-men		0.84	0.34		0.34
	-women		0.25	0.24		0.51
Hands below knees	-all	(1-5)	0.75	0.38	(1-6)	0.36
	-men		0.88	0.47		0.38
	-women		0.66	0.29		0.35
Bent or twisted body	-all	(1-5)	0.66	0.26	(1-6)	0.39
	-men		0.72	0.25		0.20
	-women		0.61	0.27		0.47
Repetitive movements	-all	(1-5)	0.58	0.61	(1-6)	0.63
	-men		0.47	0.79		0.07
	-women		0.67	0.46		0.78
Loads from 5 to 15 kg	-all	(1-5)	0.81	0.32	(1-5)	0.40
	-men		0.80	0.46		0.68
	-women		0.83	0.22		0.19
Loads exceeding 15 kg	-all	(1-5)	0.82	0.29	(1-5)	0.64
	-men		0.86	0.47		0.64
	-women		0.76	-0.03		0.55

[1] Appendix 1A describes the total number of items used for the one-year recall study, and Appendix 1B the total number of items used for the six-year recall study. Appendix 1C describes the scales used in both studies.

Validity of self-reports regarding previous physical work loads (paper II)

The correlation (r_s) between work-place measurements and questionnaire reports was high for sitting and repetitive work, moderate for perceived exertion, trunk flexion and kneeling/squatting, and poor for neck flexion and neck rotation (Table 9).

Table 9. Agreement, calculated as Spearman Rank correlation (r_s), between questionnaire responses in 1995 concerning physical load at work in 1989, and reference measurements at the work-places in 1989. Sensitivity (sens) and specificity (spec) were calculated using the work-place measurements as criterion values, and the variables were dichotomised into two classes (exposed and unexposed) by the median value. The study group was divided into subgroups according to gender and low back symptom status during the last 12 months.

Question [1]	n	% men	r_s	sens	spec
Perceived general exertion vs. heart rate:					
-all	78	36	0.52	0.65	0.74
-men	28	-	0.71	0.71	0.86
-women	50	-	0.34	0.52	0.68
-Low back symptoms	30	37	0.65	0.89	0.75
-No low back symptoms	48	35	0.29	0.45	0.73
Sitting part of the work day (scale 0-100 %):					
-all	75	37	0.73	0.79	0.81
-men	28	-	0.71	0.79	0.79
-women	47	-	0.74	0.68	0.76
-Low back symptoms	30	40	0.70	0.67	0.73
-No low back symptoms	45	36	0.76	0.87	0.86
Kneeling and squatting (scale 1-6):					
-all	64	33	0.46	0.64	0.72
-men	21	-	0.61	--	--
-women	43	-	0.40	0.63	0.67
-Low back symptoms	25	32	0.74	0.82	0.79
-No low back symptoms	39	33	0.23	0.50	0.68
Head bent forward (scale 1-6):					
-all	40	23	0.07	0.55	0.45
Head rotation (scale 1-6):					
-all	41	22	-0.16	0.25	0.62
Trunk bent forward (scale 1-5):					
-all	69	35	0.54	0.65	0.76
-men	24	-	0.56	0.67	0.92
-women	45	-	0.52	0.58	0.81
-Low back symptoms	27	33	0.48	0.70	0.71
-No low back symptoms	42	36	0.60	0.61	0.81
Repetitive work (scale 1-5):					
-all	63	32	0.62	0.81	0.69
-men	20	-	0.49	0.67	0.64
-women	43	-	0.61	0.85	0.65
-Low back symptoms	26	31	0.69	0.81	0.82
-No low back symptoms	37	32	0.58	0.80	0.59

[1] A short version of the questions and scales used is presented in Appendix.

Calculations of sensitivity and specificity showed generally higher values for specificity than for sensitivity (Table 9).

Influence of gender and musculoskeletal health

No general trend was observed in comparisons of the responses between genders or between those with or without low back symptoms, or for correlations between self-reports of the work situation in 1989 made in 1995, and work-place measurements performed in 1989 (r_s).The correlation in men between the last-mentioned self-reports and work-place measurements exceeded that in women, especially for the item perceived exertion. Higher correlation in women than in men was most pronounced for repetitive work, whereas the items sitting, kneeling/squatting, and trunk bent forward showed only minor gender differences (Table 9). The two questions on head postures yielded low correlation in women (head bent forward 0.12, head rotation –0.13), and could not be evaluated in men because of the few measurements performed.

In subjects with low back symptoms the coefficient of correlation (r_s) was higher than in those without symptoms especially for the items perceived physical exertion and kneeling/squatting. The agreement in those without low back symptoms was most pronounced for the item forward bending (Table 9).

Changes of jobs and physical work loads from 1970 to 1993 (paper III)

There were 148 men (64 % of all men in the study) working all years between 1970 and 1993, and of these 69 (30 % of all men) stayed in the same job during all those years. Of the women, 67 (27 % of all women) worked all years, and 30 of these (12 % of all women) remained in the same occupation. Among those who reported having the same occupation both in 1970 and 1993 there were no obvious difference either in rate of perceived general exertion or in PWL score, in relation to the results from the total study group, except for a somewhat higher PWL score in 1993 in men remaining in the same job (Fig. 2).

Physical work loads in relation to gender, birth cohort and age

When the intensity of the occupational physical activity was compared between 1970 and 1993 in men, the most marked changes observed were less hand vibration exposure, less lifting/carrying of loads and a larger part of the working day spent sitting down in 1993 than in 1970. Corresponding changes were not seen among women.

The rate of perceived exertion was similar in men and women, with only minor changes between 1970 and 1993 (Table 10), except for decreasing RPE values in men of the youngest birth cohort (1970 mean 13, 1993 mean 10). The proportion of the working day spent sitting increased in the men, most markedly in those born between 1950 and 1952 (1970 mean 39 % of working day, 1993 mean 60 %). In contrast, the proportion of the working day spent sitting decreased in the women, most markedly in those born between 1940 and 1944 (1970 mean 57 %, 1993 mean 47 %).

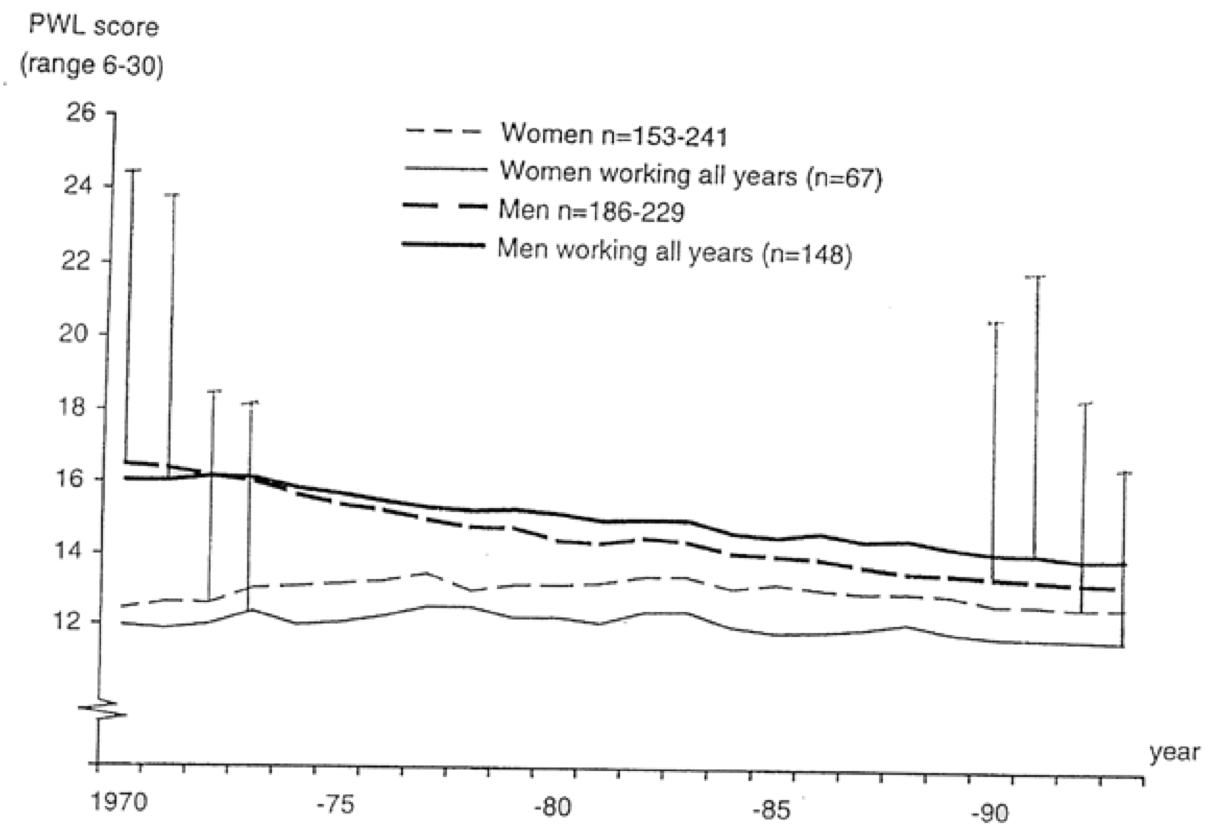


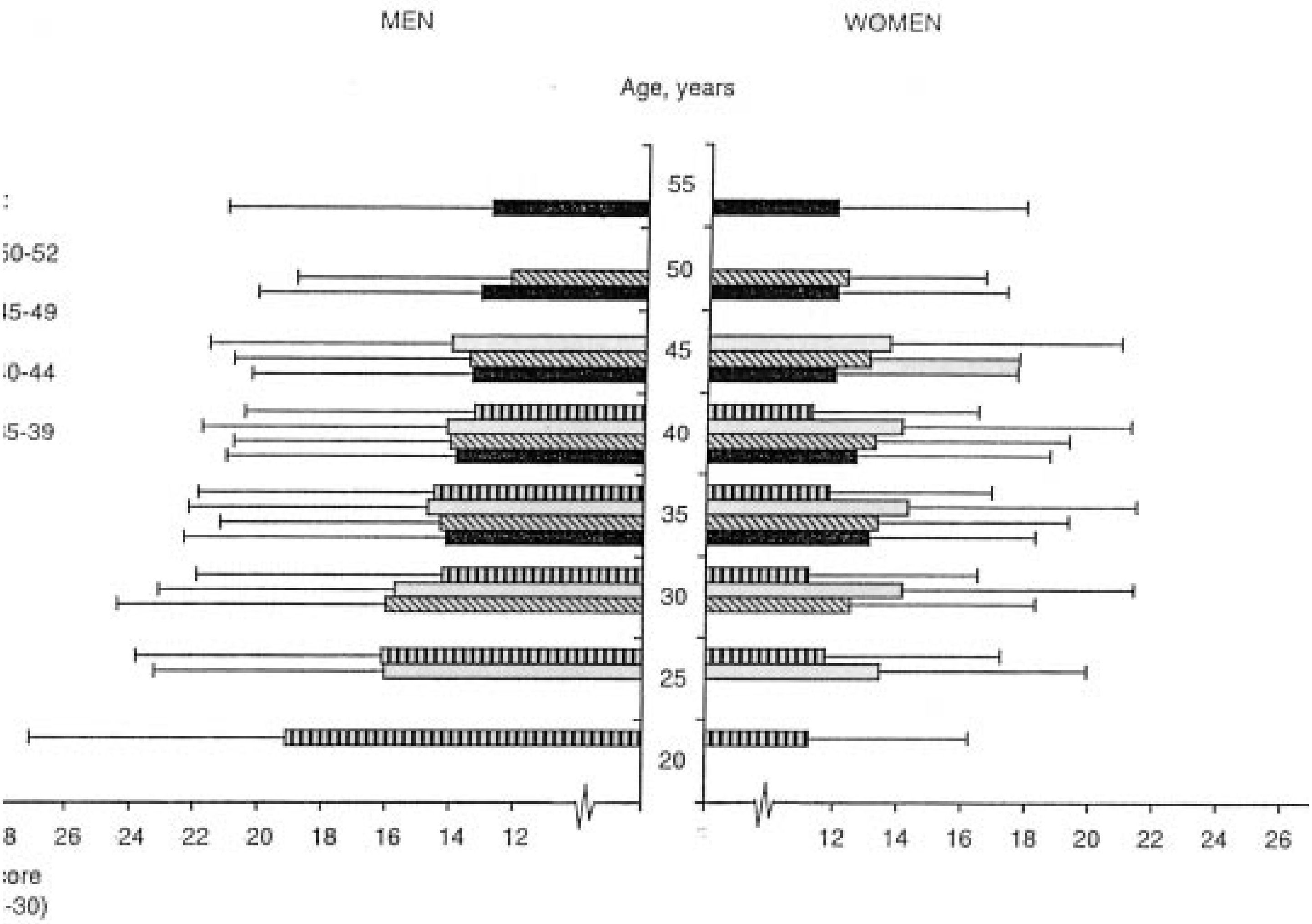
Figure 2. Annual physical work load (PWL) score, based on self-reports, between 1970 and 1993 in men and women, among those who worked all years. In the groups "men" and " women" each subject is included only in those annual va corresponding to the years during which he or she was employed. Totally there were 232 men and 252 women in the st Results are presented as mean values (M) and standard deviations (SD).

Table 10. Number (no.) of gainfully employed subjects in 1970 and 1993, their age, and measures of physical work loads (rate of perceived exertion (RPE), proportion of working day spent sitting, work with visual display terminal (VDT), and physical work load (PWL) score[1] in 1970 and in 1993, by occupational class[2] (NYK class).Age and work loads are expressed as mean and standard deviation. Totally 232 men and 252 women participated in the study.

NYK class[2]	1970: no.	age, yrs (18-35)	RPE (6-20)	sitting (0-100)	VDT (0-100)	PWL score (6-30)	1993: no.	RPE (6-20)	sitting (0-100)	VDT (0-100)	PWL score (6-30)
WOMEN											
0- prof.	24	28 (5)	10 (2)	55 (38)	5 (21)	12 (6)	52	10 (3)	48 (34)	10 (19)	12 (6)
1- health.	32	25 (4)	13 (3)	30 (32)	3 (14)	16 (5)	51	13 (2)	30 (31)	6 (16)	16 (7)
2- adm.	50	25 (4)	10 (2)	82 (17)	5 (16)	8 (3)	65	10 (2)	75 (24)	52 (29)	9 (3)
3- sales work	9	26 (4)	11 (2)	46 (32)	5 (13)	13 (4)	18	11 (3)	50 (36)	18 (23)	12 (5)
4- agricult.	1	25 (-)	8 (-)	97 (-)	0 (-)	10 (-)	3	15 (2)	39 (34)	1 (1)	20 (0)
5- mining	0	--	--	--	--	--	0	--	--	--	--
6- transp.	14	22 (3)	11 (2)	55 (40)	5 (14)	14 (5)	11	11 (3)	56 (43)	46 (41)	15 (7)
7+8- prod.	6	24 (2)	14 (3)	77 (25)	2 (2)	12 (4)	5	13 (1)	51 (45)	4 (3)	12 (4)
9- service	17	26 (3)	12 (3)	25 (39)	1 (1)	17 (4)	20	13 (3)	26 (38)	8 (22)	17 (6)
All employed	153	25 (4)	11 (3)	56 (37)	4 (14)	12 (5)	225	11 (3)	50 (36)	23 (31)	12 (6)
MEN											
0- prof.	52	27 (4)	10 (2)	50 (33)	3 (3)	12 (6)	66	10 (2)	65 (28)	23 (26)	10 (4)
1- health.	2	24 (2)	12 (1)	40 (26)	2 (2)	11 (1)	3	12 (2)	78 (15)	44 (42)	10 (2)
2- adm.	21	27 (5)	9 (2)	72 (29)	4 (10)	9 (4)	43	9 (2)	73 (28)	46 (29)	8 (3)
3- sales work	14	29 (4)	11 (3)	51 (32)	0 (1)	12 (5)	27	10 (3)	63 (30)	24 (27)	11 (5)
4- agricult.	2	20 (1)	16 (1)	24 (7)	0 (0)	27 (1)	2	13 (0)	9 (12)	0 (0)	26 (3)
5- mining	2	23 (1)	16 (2)	4 (5)	0 (0)	25 (4)	1	15 (-)	0 (-)	0 (-)	30 (-)
6- transp.	13	27 (4)	14 (2)	40 (40)	1 (2)	19 (8)	14	12 (3)	69 (33)	9 (24)	15 (6)
7+8- prod.	70	26 (4)	14 (2)	26 (33)	1 (3)	22 (7)	50	13 (2)	25 (31)	8 (16)	21 (7)
9- service	10	25 (5)	13 (3)	31 (37)	0 (0)	18 (7)	5	13 (1)	51 (38)	26 (21)	18 (7)
All employed	186	26 (4)	12 (3)	41 (36)	2 (7)	16 (8)	211	11 (3)	56 (35)	23 (28)	13 (7)

[1] PWL score - based on items on standing/walking, hands high, forward bending, twisted trunk postures, and manual handling of loads.

[2] 0=Professional, technical and related work. 1=Health and nursing work, social work. 2=Administrative, managerial and clerical work. 3=Sales work. 4=Agricultural, forestry and fishing work. 5=Mining, quarrying and petroleum extraction work. 6=Transport and communication work. 7+8=Production work. 9=Service work.



sical work load (PWL) score among men and women in relation to birth cohort and age. Each subject takes part only in t
onding to the years during which he was employed. Totally there were 232 men and 252 women in the study. Results ar
M) and standard deviations (SD).

The proportion of the working day spent using a VDT increased substantially between 1970 and 1993, in both men and women (Table 10). The proportions of the working day with whole body vibrations, precision work, and repetitive finger/hand work were low and approximately unchanged between 1970 and 1993, in both genders.

The PWL scores decreased during the period 1970 to 1993 in the men, but not in the women. On the contrary, a slow increase in PWL scores, with the highest values in the beginning of the 1980s, was seen in the women (Fig. 2). The men who worked in all the years between 1970 and 1993 showed slightly higher PWL scores than the whole male group, in contrast to the women working all the years, whose PWL scores were lower than those of the whole female group (Fig. 2). The PWL scores were in general higher in men than in women at younger ages, but the difference was less pronounced at higher ages. The gender difference in PWL scores was most marked in the youngest birth cohort (born 1950-52) and least marked in those born between 1940 and 1944 (Fig. 3).

The LB scores decreased during the follow-up period in men but not in women, in contrast to the N/S scores, which decreased in both genders. Men showed higher LB scores than women in the beginning of the follow-up period, but thereafter the scores were approximately equal.

Higher variance (CV %) was generally found for self-reports of physical work load (PWL scores) than for expert evaluations based on job titles (LB and N/S scores), especially in the oldest female birth cohort (PWL score 14 %, LB score 9 % and N/S score 8 %).

Physical work load in relation to occupational class and education

The proportion of the working day spent sitting decreased from the year 1970 to 1993 in women in many occupational classes, e.g. “professional/technical work” and “administrative work” (Table 10). In contrast, this proportion increased in most occupational classes among the men.

The PWL scores decreased between 1970 and 1993 in men in most occupational classes, in contrast to the women, who showed mainly unchanged PWL scores (Table 10). Among men with at least 10 subjects working both in 1970 and 1993, the highest PWL score was found for “production work”, and the lowest score for “administrative work”. Among the corresponding women, the highest PWL score was seen for “service work”, and the lowest score for “administrative work ”.

The level of education in 1993 covaried with PWL score level in men, i.e. the PWL scores were higher in those with a low level of education (not more than 9 years of compulsory school) and lower in men with university/college education. This pattern was not found among the women, in whom the PWL scores were similar in those with a low and a high level of education.

Physical performance in middle-aged men and women

Physical capacity (paper IV)

Isometric maximal strength in Newtons (N) in women was about 60 % of that in the corresponding male age group. The highest female/male ratio was found for trunk extension strength in younger subjects (65 %) and the lowest ratio for trunk flexion strength in older subjects (54 %). When muscle strength results were corrected for body surface area ($N \cdot m^{-2}$), the female/male ratio increased to about 70 %. The differences between age groups were similar when muscle strength was expressed in Newtons and in Newtons per body surface area; on average the strength was 6 % lower in older men and 7 % lower in older women, and the smallest difference was found for hand grip strength (Table 11).

Dynamic endurance in women was about 65 % of that in the corresponding male age groups, with the highest female/male ratio for number of curl-ups in older subjects (76 %) and the lowest ratio for number of squats in older subjects (48 %). The difference between age groups in men was on average 17 % lower and in women on average 30% lower in the older group, the largest difference being found for squatting in women (Table 12).

Maximal oxygen consumption in the younger and older female groups was about 79 % and about 88 %, respectively, of that in the corresponding male age groups, and physical fitness showed even smaller gender differences (Table 12). The differences between age groups were about 16 % in men and about 6 % in women for both measures of aerobic power.

Sensory thresholds (paper V)

The pressure pain thresholds in men exceeded those in women, with the female value about 70 per cent of the corresponding male value, at all locations tested (Table 13). The vibration thresholds on the hand showed similar values in men and women, but on the right foot men had higher values than the women. The values for cold and warm perception thresholds were similar in men and women, although women were slightly more sensitive for both modalities. The heat pain threshold in men exceeded that in women. There were no obvious differences in sensory thresholds between the two age groups, except for lower PPT on the right tibia in the older male group, and higher vibration thresholds on the foot in the older group of both men and women (Table 13).

Physical performance in relation to individual factors (paper IV)

About half of the study population reported regular high- or medium-intensity physical training at least once a week in 1993, but this had decreased somewhat from earlier decades, especially among older men. About one-third of the subjects were smokers in 1993, with an approximately equal prevalence among men and women. Musculoskeletal symptoms during the last week before the examination were common among both men and women, especially in the neck, shoulder and low back areas.

Table 11. Isometric maximal muscle strength for back flexion, back extension, hand grip (right hand) and knee extension (right leg). The results are presented as Newtons (N) and as Newtons per body surface area (N . m-2) in relation to gender and age group (41-49 years, 50-58 years). Data are presented as mean values (M), standard deviations (SD) and the 25th (P25) and 75th (P75) percentiles.

	MEN						WOMEN					
	41-49 years n=148			50-58 years n=84			41-49 years n=170			50-58 years n=82		
Test	M	SD	P25-P75	M	SD	P25-P75	M	SD	P25-P75	M	SD	P25-P75
Back flexion												
Newton (N)	750	181	629-841	706	139	625-792	410	99	342-473	379	100	313-446
(N . m-2)	376	84	327-419	353	58	316-390	238	51	204-273	218	49	186-251
Back extension												
Newton (N)	974	174	855-1098	925	188	794-1037	636	144	536-730	589	137	495-674
(N . m-2)	488	81	435-548	463	85	403-514	370	80	319-423	339	73	292-404
Hand grip												
Newton (N)	524	89	464-587	501	105	444-560	290	64	254-334	279	54	247-315
(N . m-2)	263	40	232-292	251	48	219-279	169	36	150-193	161	29	143-178
Knee extension												
Newton (N)	465	95	391-525	434	87	388-500	285	62	246-325	265	58	223-303
(N . m-2)	233	47	199-262	218	42	196-242	166	35	143-188	153	34	130-175

Table 12. Dynamic muscle endurance, and calculated maximal oxygen consumption. The results are presented as mean values (M), standard deviations (SD) and the 25th (P25) and 75th (P75) percentiles, in relation to gender and age group (41-49 years, 50-58 years). The endurance tests were stopped at 50 curl-ups, exertions or lifts.

	MEN						WOMEN					
	41-49 years n=148			50-58 years n=84			41-49 years n=170			50-58 years n=82		
Test	M	SD	P25-P75	M	SD	P25-P75	M	SD	P25-P75	M	SD	P25-P75
Curl-up[1] (no. of curl-ups)	30	14	22-40	25	12	17-31	21	13	12-30	19	15	8-27
Squatting[2] (no. of exertions)	33	18	20-50	29	18	16-48	23	16	10-33	14	17	0-19
Weight lifting[3,4] (no. of lifts)	20	10	14-25	17	9	11-23	25	14	15-34	22	13	14-32
Maximal oxygen consumption												
($l \cdot min^{-1}$)	2.9	0.6	2.4-3.3	2.5	0.5	2.1-2.9	2.3	0.4	2.0-2.5	2.2	0.4	1.9-2.5
($ml \cdot min^{-1} \cdot kg^{-1}$)	35	8	30-40	30	7	25-36	35	7	30-40	33	7	28-37

[1] 50 curl-ups were performed by 16 %, 6 %, 5 % and 6 % of the subjects in the above four groups

[2] 50 exertions were performed by 36 %, 23 %, 15 % and 13 % of the subjects in the above four groups

[3] 50 lifts were performed by 1 %, 0 %, 10 % and 6 % of the subjects in the above four groups

[4] 10 kg weights in men, 5 kg weights in women

Table 13. Sensory thresholds in middle-aged men (n=232) and women (n=252).

	MEN						WOMEN					
	41-49 years n=148			50-58 years n=84			41-49 years n=170			50-58 years n=82		
Test	M	SD	P25-P75	M	SD	P25-P75	M	SD	P25-P75	M	SD	P25-P75
Pressure pain thresholds (kpa)												
Right hand dig III, PIP	727	263	531-874	713	263	523-863	511	183	389-631	511	162	386-642
Right hand, thenar area	693	239	524-834	676	248	507-843	479	177	345-579	458	150	331-538
Right trapezius	493	222	346-602	480	198	333-628	308	150	202-380	323	139	230-430
Right tibia	563	198	424-654	497	186	373-603	376	134	277-455	352	133	269-429
Vibration thresholds (µm)												
Right hand MC II	0.5	0.3	0.3-0.5	0.5	0.3	0.3-0.6	0.4	0.4	0.2-0.5	0.7	1.1	0.3-0.6
Right foot MT I	2.1	3.7	0.6-2.0	4.3	6.6	0.7-5.6	1.0	1.4	0.4-1.1	1.5	1.8	0.5-1.9
Thermal thresholds[1] (°C)												
Cold perception												
Right hand, thenar area	1.1	0.4	0.9- 1.2	1.3	0.9	0.9- 1.3	1.0	0.3	0.8- 1.1	1.1	0.4	0.8- 1.2
Right foot, below lateral malleolus	2.6	1.7	1.6- 3.2	2.8	1.4	1.5- 3.6	2.5	1.4	1.7- 3.0	2.7	1.6	1.4- 3.5
Warm perception												
Right hand, thenar area	1.6	1.0	1.2- 1.7	1.7	0.6	1.2- 1.9	1.2	0.4	1.0- 1.4	1.3	0.5	1.0- 1.5
Right foot, below lateral malleolus	4.9	2.2	3.2- 6.2	5.4	2.6	3.5- 7.0	3.7	1.7	2.6- 4.5	4.2	1.8	3.1- 4.9
Heat pain perception												
Right hand, thenar area	14.3	3.0	12.5-16.6	14.0	2.9	11.8-16.5	12.7	2.9	10.8-14.9	13.3	3.0	11.5-15.3
Difference perception (warm/cold) hand[2]	2.7	1.2	2.1- 2.9	2.9	1.2	2.1- 3.2	2.2	0.6	1.8- 2.5	2.4	0.8	1.9- 2.7
Difference perception (warm/cold) foot[3]	7.6	3.3	5.3- 9.2	8.1	3.3	5.6-10.1	6.1	2.3	4.7- 7.2	6.9	2.8	4.9- 8.4

[1]Both warm and cold perception thresholds and heat pain thresholds refer to 32 °C as the baseline temperature

[2]Warm perception threshold + cold perception threshold, right hand

[3]Warm perception threshold + cold perception threshold, right foot

Lack of regular physical training were related to low dynamic endurance and low physical fitness in both genders, but to a lesser extent to low isometric strength. In women the prevalence of low physical fitness was 1.8 times higher (CI 1.2-2.9) and that of curl-up 1.7 times higher (CI 1.1-2.7) among subjects who did not train on a regular basis compared to those who did. The corresponding results in the men were PR 3.3 (CI 1.9-5.8) concerning physical fitness and PR 1.6 (CI 1.0-2.7) concerning curl-up.

Associations between current smoking and low physical capacity were only seen for isometric muscle strength per body surface area in the men and were most pronounced for leg extension strength (PR 1.9, CI 1.2-3.0).

Musculoskeletal symptoms during the last week frequently showed associations with low maximal isometric strength per body surface area and dynamic endurance in both genders. In women, the most pronounced associations were noted for hand grip strength (PR 2.3, CI 1.6-3.4) and weight, lifting endurance (PR 2.0, CI 1.3-3.2). In men the most marked associations were seen for squatting endurance (PR 2.3, CI 1.5-3.6) and trunk extension strength (PR 1.8, CI 1.2-2.7).

Physical capacity in relation to occupational work load (paper IV)

The associations between physical capacity and PWL score differed in relation to length of time period, gender and the kind of capacity tested. For trunk flexion strength per body surface area in women, a positive significant association between high PWL score and low strength was found for exposure periods of ten years or more (PR 1.7, CI 1.0-2.5). This was not observed in the men. A high PWL score was associated with low squatting endurance in both men and women for long exposure periods (PR 1.7, CI 1.0-3.5), and with low physical fitness for long exposure periods in women (PR 1.8, CI 1.0-3.1). The remaining results showed mainly weak to moderate inverse relations to PWL score in both genders. This was especially obvious for weight-lifting endurance and for hand grip strength per body surface area in relation to PWL score. In women this was found only close in time (hand grip PR 0.5, CI 0.3-0.8), but in men it was independent of the length of the time period (hand grip PR 0.3, CI 0.2-0.7). Post hoc analyses of associations between high PWL score and high strength per body surface area showed positive significant associations for hand grip strength (PR 2.5, CI 1.4-4.5) and weight lifting (PR 1.9, CI 1.0-3.6) in men, but not in women.

No significant effect modification by age, physical training habits, smoking habits or musculoskeletal symptom status was observed in the relationship between PWL score level and different measures of physical capacity. The results of the multivariate analyses showed no obvious discrepancies regarding the relation between physical work loads and physical capacity, whether calculated with or without these variables, indicating only minor confounding in this data set.

The relations between physical capacity and single physical work-loads relevant to the body parts tested were also examined. However, no particular work-load component dominated the results, except for a significant association between frequent heavy lifts (> 15 kg) and weight lifting endurance in the men (PR 0.5), indicating a possible training effect.

Sensory thresholds in relation to selected covariates (paper V)

Multivariate analyses of sensory thresholds in relation to the independent variables presented above showed increasing pressure pain thresholds in relation to muscle strength in both men and women (men: p range 0.05-0.001; women: all <0.001). In men, the pressure pain thresholds were also positively related to physical work load and smoking. However, in women they were negatively related to smoking. In women there was also a tendency to a positive relation between pressure pain thresholds and body height. Pressure pain thresholds in both men and women were often positively, but not significantly, related to age.

Multivariate analyses of vibration thresholds showed that the vibration threshold on the foot was positively related to age and body height in both genders (men: age $p=0.01$ and body height $p<0.001$; women: age $p<0.001$ and body height $p<0.001$). The vibration threshold on the hand was related to hand/wrist symptoms in women ($p=0.001$), but not in men.

Multivariate analyses of thermal thresholds for warm and cold perception showed similar results in men and women. Significant relations were mainly found regarding thresholds on the foot, with a positive relation to age and body height for warm perception (men: age $p=0.002$ and body height $p<0.001$; women: age $p=0.03$ and body height $p<0.001$), and a negative relation to skin temperature for cold perception ($p<0.001$) in both genders. The heat pain threshold on the hand was positively associated with muscle strength ($p=0.009$) in men, and positively associated with age ($p=0.003$) and aerobic power ($p=0.009$) in women.

Discussion

Methodological considerations

Generalizability

The present study group was originally recruited from the Stockholm county area (except Stockholm city) in 1969 and is still considered to be a representative sample of the middle-aged urban and sub-urban Swedish population and thus also probably representative of the physical work load development (work career) in the birth cohorts in question during the last two and a half decades. Due to the original selection of the subjects, white-collar workers (e.g. professional work, administrative work) are overrepresentated in the study group in relation to the general Swedish population born between 1935 and 1952. Beside the above mentioned initial selection of study subjects in 1969 there were also additional selections of subjects, both an intentional and an possibly unintentional (the drop-outs) selection.

There intentional selection of subjects excluded subjects with muskuloskeletal diagnoses and some other serious diagnosis in the REBUS-70 study from participation in the follow-up in 1993. This was done in order to achieve incident cases of musculoskeletal disorder during the follow-up period (results not used in the present investigation) and because those subjects would probably be less able to join the work force during follow-up, possibly diluting true correlation between work exposures and outcome variables.

Possible unintentional selection among the drop-outs was evaluated by comparing information among the participants (484 subjects) and the drop-outs (299 subjects), using the national LOUISE database (Statistics Sweden SCB, 1998) and information from the REBUS-70 study. The drop-outs were found to have lower educated, lower income and a lower work-force participation rate than those participating in the REBUS-93 study, especially so among the older women (Bildt Thorbjörnsson, 1999). The drop-outs were also found to have more health problems in the initial REBUS study in 1970, than the participants. The impact on calculated risk estimates of musculoskeletal morbidity, by the selections processes described above, was found limited (Bildt Thorbjörnsson, 1999) and thereby probably also indicating limited impact on calculated risk estimates in the present investigation. However, some physical capacity results might have been influenced by a possible îhealthî selection, e.g. higher results on aerobic power among older women (50-58 years) than among younger (41-49 years).

Paper I

The appropriateness of the use of two different study groups for reliability testing and of the relatively small size of one of the study groups in study I may be questioned. However, these subjects, all chosen from the main study, had to be shared between different research projects, with evaluations of several instruments for measuring exposure and outcome, and a limit had to be placed on the number of questionnaires to be answered by the individual subjects.

Opinions differ concerning the ideal interval between a test and retest. Two weeks may be considered too short to prevent the subjects from remembering the previous answers to the questionnaire, which could result in falsely elevated reliability figures (Carmines et al., 1979). But the level of reproducibility in the one-year retest group was similar to that in the two-week retest group, suggesting that the memory of previous answers was not an important factor for the retest results in the two-week group. Besides, the subjects also answered several other questionnaires during the day of examination and interview in 1993, which would have made it more difficult to remember these particular questions.

Papers II and III

Many of the subjects in study II and III were working in the same occupations for long periods of time, a fact likely to lead to an underestimation of memory difficulties in questions about historical physical work loads. However, there have been several major changes in the labour market in Sweden during the last two decade (e.g. technical and organisational) which would probably have meant a different physical exposure situation even if the subjects have been staying in the same occupation. In male group (232 men), 37 % of the variance in the 1993 PWL scores could mathematically be explained (based on correlation matrix values) by the PWL scores in 1970, with the highest fraction in men of the oldest birth cohort (80 %) and the lowest in men in of youngest cohort (25 %). The corresponding figures in the female group (252 women) was 19 %, with the highest fraction in women of the oldest birth cohort (36 %) and the lowest in women of the youngest cohort (1 %). These results indicates that there are a substantial amount of other factors influencing self-reported physical work load, besides previous load.

Papers IV and V

Tests of physical performance in these studies were chosen in order to cover a broad spectrum of abilities important in relation to physical demands in at work. Physical work ability has been related to three major components, strength, endurance and movement quality, independent of job type and individual performance (Hogan, 1991). The tests to be used in middle-aged population groups also have to bee safe and cause a minimum of risks for overstrain injuries. Sensory thresholds in study V were chosen in order to cover different sensory modalities and different types of fibres in afferent cutaneous nerves.

Musculoskeletal symptoms were regarded as possible confounders in study IV, as low results might be due to fear of more symptoms and not to “real” muscular weakness. No doubt, symptoms and especially pain are sometimes part of the mechanism by which work load may affect physical capacity, so keeping symptoms as a confounder in the final analyses might dilute the true association. However, the associations between capacity and physical work load did not change (either point estimates or confidence intervals) when symptom status was introduced as a separate variable in the model. This indicates that present musculoskeletal symptoms exerted only a minor influence on the relationship between heavy physical work and physical capacity.

Muscle strength is known to be related to muscle mass (Viitasalo et al., 1985), which in turn is related to several factors such as body seize, heredity, gender, age, and training by physical exercise or work. In theory there is a close relationship between the cross-sectional surface area of the muscle and force output. By relating the strength results to the square of the body height (Åstrand et al., 1986) an attempt is made to correct the maximal isometric strength for body size. This might be sufficient when studying subjects with similar body proportions, but in this study with a wide variation in proportions, from tall and slender to short and athletic, we chose to relate the strength results to the body surface area. This decision was based on the results of calculations of correlation between different body dimensions and maximal isometric strength, where the highest correlation was found in relation to the body surface area, a finding in accordance with the results of a previous Swedish population study of healthy men and women (Stålberg et al., 1989). An other way of correcting muscle strength for body seize would have been to relate the strength results to the external moment arm length assuming a direct correlation between external and internal moment arm length. However, correlation between external body dimensions and internal moment arm length are sometimes difficult to demonstrate (Reid et al., 1987).

Reliability of self-reported physical loads

In research on musculoskeletal disorders, information is required about the occurrence of physical activities throughout the whole life span, so that cause-effect relationships can be investigated. Some musculoskeletal disorders are likely to be related to current loads, while others may be caused by peak or accumulated exposures (Hagberg, 1981; Vingård et al., 1991a). The discrepancies between current, previous and average physical work exposure has been found to increase with the age of the subject, and the use of current exposures or job titles has been considered inadequate for studies of subjects of varied occupations and age classes (Gibbons et al., 1995). Long-term prospective investigations with repeated measurements of exposure can partly overcome these problems, but such studies have other drawbacks, such as high costs, drop-outs, and difficulties in maintaining the same measurement technique over time.

The reliability of an instrument can be evaluated by several techniques, often starting with reproducibility studies, which give the upper limit for the possible reliability of the instrument, and are often carried out as test-retest reproducibility (intra-method reliability) studies. But other evaluations are needed to ascertain that the instrument is actually measuring what it is meant to measure, and these are often carried out by parallel use of a well-known previously evaluated “golden standard” (tests of validity). However, suitable “golden standards” are seldom available and these studies are therefore often performed by parallel testing (inter-method reliability) (Burdorf, 1995).

A major concern in epidemiological studies of physical workloads and musculoskeletal health is whether the musculoskeletal symptom status may cause differential misclassification of exposure. If so, the point estimates can be either under- or overestimated, depending on the direction of the bias. In view of possible gender differences, agreement between questionnaire responses and work-place measurements in relation to the musculoskeletal symptom status should preferably be evaluated in groups with a similar gender distribution. This was the case regarding low back symptoms in study II, when men constituted approximately 35 per cent both of the group with and that without symptoms. A comparison of the subjects with and without symptoms did not indicate any tendency for subjects with symptoms to report higher or lower exposure levels than symptom-free subjects. However, the precision of the questionnaire responses (random error) can still cause differential misclassification if subjects with musculoskeletal symptoms remember their previous work loads more exactly than those without symptoms. Rank correlation coefficients among subjects with low back symptoms during the last 12 months differed from the corresponding correlations among those without symptoms with regard to only a couple of items. But, these differences in agreement between symptom groups were not associated with differences between calculated prevalence ratios based on questionnaire responses (PR_{quest}) and those based on reference measurements (PR_{ref}). Thus there appears to be no serious differential misclassification of exposure related to musculoskeletal symptom status in the REBUS study group. This conclusion is in accordance with a previously reported evaluation of present physical work loads in the Stockholm-MUSIC and the MUSIC-Norrtälje studies (Wiktorin et al., 1993; Wiktorin et al., 1999), but not with the results of a study of forest industry workers in Finland (Viikari-Juntura et al., 1996), where self-reported physical load was overestimated among those with severe low-back pain. However, in the REBUS study the subjects were instructed to change the day of examination in the event of acute musculoskeletal symptoms, and this might possible have reduced bias due to ongoing symptoms.

The test-retest reproducibility of responses to questions about the intensity of different physical loads in study I showed no obvious trend to deteriorate for more distant years, compared to the present year. This is encouraging, since stable reproducibility over time is one of the requirements for use of questionnaire information about previous physical activities. But the question may arise as to whether this lack of deterioration is due to sufficient memory of past exposures or to the possibility that the subjects were just repeating their present work situation to apply to the whole follow-up period. However, a majority of the subjects reported changes in work loads during the follow-up period, most of them reported more than one occupation during the follow-up period, and many changed their occupation during the last five years before examination in 1993, which was a dynamic period of time on the Swedish labour market. Of course it is impossible to check what the subjects were actually thinking when they filled in the questionnaire, but we believe that the procedure used, based on individual work histories, was of major importance for the acceptable reproducibility results obtained for the majority of the items. The differences between the two-week, one-year, and six-year reproducibility results, presented in Table 6 and 8, which mainly show gradually decreasing correlation coefficients in parallel with an increasing time interval between test and retest, may be regarded as an indicator of the extent to which reproducibility is affected by increasing memory difficulties. However, some caution is recommended when comparing these results as they include comparisons between study groups with somewhat different response distributions, and a wider distribution of item responses may in itself lead to higher correlation coefficients (Armstrong et al., 1992).

The test-retest reproducibility for exposures at work clearly exceeded that for leisure-time exposures in most cases (Tables 6 and 7), possibly on account of the way in which the questions were presented to the subjects. Questions about activities at work were based on the individual lengths of time in different occupations, and the activities may therefore have been more easily remembered, while questions about leisure-time activities were based on the same specified five-year periods in all subjects. Leisure-time physical activities may also vary more than those at work (e.g. between seasons and years), and may therefore be more difficult to recall. The questions regarding leisure-time activities asked in study I thus need to be improved before their use in epidemiological studies of relationships between leisure-time physical activities and musculoskeletal health can be recommended. Improvements might perhaps be achieved by use of a life events calendar technique, which has been found successful for exposure assessments regarding exposures throughout working life (Hoppin et al., 1998). These techniques probably involve additional effort and costs, since they are interviewer-administered rather than self-administered, but this might be a way of achieving reliable information on the “off work” loads.

The validity of self-reported exposures was assessed as “good” for some of the items that could be evaluated in relation to work-place measurements (Table 9). The results for the item kneeling and squatting showed less agreement than in a previous study (Wiktorin et al., 1993), and those for head postures were quite poor, but in line with the findings of Wiktorin and co-workers. Comparisons between the validity of self-reported physical work loads at present (Wiktorin et al., 1993) and in the past (paper II) could be made for six items with comparable cut-off points in the two studies. Approximately unchanged and acceptable correlation values were found for daily time spent sitting and for forward bending of the trunk. Unchanged, low agreement was noted for the item head rotation, and decreased agreement for kneeling/squatting and for forward bending of the head.

In both men and women, the expert scores for low back load (LB score) during the follow-up period in study III showed a pattern similar to that of self-reported physical loads (PWL score), which may be regarded as a sign of validity of the self-reported work loads. As expected, less variance of exposure was found with use of expert scores based on job titles compared to self-reports, as a result of loss of variance among those who remained in the same job for many years. This loss seemed to be most marked in the oldest birth cohort, which is in accordance with results from other studies (Gibbons et al., 1995).

The questionnaire used in the REBUS study was constructed on the basis of experiences from the Stockholm-MUSIC study, but with focus on physical work loads in the past, and in the general population, and some changes in the wordings of items and the response scales were therefore considered necessary. These changes limited the questionnaire responses that could be validated in relation to work-place measurements performed in 1989, and the cut-off levels between exposed and non-exposed groups of subjects regarding questionnaire responses and reference measurements could not be matched exactly, because of incomparability between the scales used. The sensitivity and specificity values presented in Table 9 are therefore based on categorisation of the subjects into exposed and non-exposed classes by the median values (P50) of questionnaire responses and of reference measurements.

Age and gender aspects of physical load and work career

Physical work load measured as PWL score decreased during the last two decades, especially in younger men, mainly on account of a reduction in manual handling (paper III). This reduction was partly due to changes to white-collar occupations among the men, but also probably to changes in work methods and work place reorganisation in the direction of less physically demanding work tasks during the studied time period. No similar reduction in physical work load during this time period seemed to have taken place in occupations dominated by female workers, e.g. service and health/social work. Many of the older women in the present study entered the labour market in the late seventies during the expansion of the public sector in Sweden, and started to work in these branches, and subsequently they often stayed in the same occupations. These traditionally female occupations are dominated by direct manual and individual contacts with other people, i.e. by work tasks that have not been mechanised in the same way as tasks in administrative and industrial occupations, and this is probably the main reason for the unchanged physical work loads among the women during the follow-up period.

The physical work load "career" was found to be related not only to gender but also to birth cohort, though differently among men and women. This was especially noted in the youngest birth cohort (born in the early fifties), with decreasing physical work loads among men but constantly low loads among women. Concerning the women, this might be explained by the fluctuating need for new employees in the public sector. That is, in times of public sector expansion women will enter jobs with high physical work loads and usually few natural career possibilities. This is in agreement with reports of today of a generation gap in the health and service sector, with mainly older women (born in the thirties and forties). An unchanged, high physical work load was also found among the men who had remained in physically demanding jobs (production work), but transfer to less demanding jobs was common.

In a health perspective, equal or increasing work loads in women at the age of 50 compared with the work loads 25 years earlier in physically demanding jobs give reason for concern, in the light of the expected decrease in physical capacity with age (Ilmarinen, 1992a; Ilmarinen, 1992b). However, the rate of perceived exertion, which is regarded as a measure of the balance between external load and individual capacity, was unchanged in women during the follow-up period (Table 10), indicating unchanged strain despite a possibly decreased capacity. But the development of RPE during the follow-up period differed between NYK classes, and in women in service work (e.g. cleaners, and workers in restaurants and in the home care service), increasing RPE was noted, in line with other reports of high work loads among older women in these jobs. The suitability of high physical work loads in older workers has been questioned, especially after the age of 50 (Lusa et al., 1994; Oja et al., 1977). The finding of equal physical work loads (PWL scores) among the women in the present study in 1993 compared to 1970 was partly due to a decreased fraction of the working day spent sitting. This was especially noted among women in professional and administrative work, and hopefully also indicates more stimulating and varied work tasks in these occupations. However, prolonged standing has been identified as a risk factor for reduced work ability in a 10-year longitudinal study of Finnish municipal employees (Tuomi et al., 1997), and has been related to sensations of fatigue and foot discomfort (Messing K and Kilbom Å, in press). In men, an increasing fraction of the working day sitting down during the follow-up period was reported especially in connection with sales work and in transport and communication work; this was possibly related to an increase in both vehicle driving and office work in those occupations.

The present results contrast somewhat with the findings of increased self-reported physical work loads over time (1981- 1992) in both men and women in a longitudinal study of Finnish municipal workers (Nygård et al., 1997). An increasing prevalence of health symptoms and a decreasing work capacity with age were suggested as reasons for the higher self-reported work loads compared to objectively assessed loads in the Finnish study (Nygård et al., 1995). The subjects in the present study started with their work situation in 1993 and were then asked about their earlier jobs, which perhaps meant that their responses were less influenced by present symptoms. The difference in the development of self-reported loads between studies could also be due to other factors such as differential changes in work loads over time in different sectors of the labour market, and to higher age and a higher prevalence of blue-collar occupations in the Finnish study. But regarding the age aspect, the healthy worker effect would perhaps have acted in the opposite direction, i.e. by keeping only those who could easily cope with their physical work demands despite increasing age.

Muscle strength and aerobic power in middle-aged subjects

The isometric strength results for subjects in the REBUS study are in accordance with the results of other recent Nordic studies of mixed occupational groups

(Bäckman et al., 1995; Nygård et al., 1994; Nygård et al., 1987), except for higher back extension strength in REBUS-93 than in a study of municipal workers in Finland (Nygård et al., 1987). The dynamic endurance results are consistent with the findings in a recent Finnish study (Alaranta et al., 1994), whereas the results for aerobic capacity are somewhat higher among the women in the REBUS study than in others of similar age (Ilmarinen et al., 1991a; Jackson et al., 1995; Jackson et al., 1996). Previous studies have shown an approximately 20 % lower relative aerobic capacity in women than in men, a difference due to a higher percentage of lean body mass in the men. However, this was not seen in the REBUS study, where an equal or even lower aerobic capacity and a higher BMI was found in the men compared with the women. These results are in line with results in other recently published studies of Swedish general population samples (Barnekow-Bergkvist et al., 1996; Engström et al., 1993; Kilbom et al., 1991), and might probably be related to changes in physical training habits and physical work activity patterns during the last decades in Sweden. Systematic gender-dependent errors in estimations of aerobic power could be related to attenuation of a "true" gender difference, and systematical under-evaluation of aerobic capacity has been seen in men, and over-estimations in women (Kilbom et al., 1993). However, this was mostly observed in subjects below 35 years of age and thus cannot explain the results of the REBUS study. An, other reason might be a gender-specific health selection to the REBUS study, i.e. inclusion of more physically fit women, and/or more less fit men in the study. The highest fraction of drop-outs was found among the older women (between 50 and 58 years of age), possibly indicating a health selection especially in that group. This indication is supported by the findings in a recently published thesis where these women reported more health problems already at the original REBUS study in 1970, than the those of corresponding age who participated in the follow-up in 1993 (Bildt Thorbjörnsson, 1999).

Sensory thresholds in middle-aged subjects

Significant gender differences were noted for all thresholds, with higher thresholds in men, except for vibration threshold on the right hand and cold perception threshold on the right foot. Gender differences in sensory thresholds are often reported, especially for pain thresholds. Several factors have been suggested as explanations of those differences, e.g. speed of reaction, relation of receptor density to body size, sex-role expectation, nociceptive discrimination capacity, temporal summation and patterns of cerebral activation (Feine et al., 1991; Fillingim et al., 1998; Lautenbacher & Strian, 1991; Paulson et al., 1998; Stevens & Choo, 1998). But there are still doubts as to whether there are any basic gender differences in sensory perception.

Relations between measures of physical capacity and sensory thresholds have not been reported in the literature, except for a finding of low vibration thresholds in men with a short reaction time and high leg extension velocity in a Finnish study (Era et al., 1986), and high pressure pain thresholds in subjects with high grip strength in a mixed study of hand surface sensitivity (Fransson-Hall et al., 1993). In study V physical capacity expressed as muscle strength corrected for body size was positively related to pressure pain thresholds in both genders, and was slightly inversely related to vibration and cold temperature thresholds on the foot in men. This indicates that subjects with high muscle strength have less pressure pain sensitivity and improved perception ability for vibrations and temperature changes. Muscle strength was corrected for body size and the results should thus not only be related to differences in skin receptor density. Moreover, lower skin receptor density among subjects with high muscle strength should have resulted in higher and not lower vibration and cold thermal thresholds. The perception of pressure pain is probably mainly mediated by multimodal nociceptors in muscles (in the walls of arterioles) and in the connective tissue, and a larger amount of muscle tissues might perhaps be related to receptors adapted to higher local forces. However, modified pressure pain perception could perhaps also be due to a change in sensitivity of second order dorsal horn cells, altered processing of afferent signals at the thalamic level, or changed cortical projection. Physical fitness (calculated as VO_2 max rel) was not related to any sensory threshold in men, but was significantly related to warmth perception threshold and heat pain thresholds on the hand in women (i.e. heat perception was improved and heat pain sensitivity was reduced in women with high physical fitness).

Despite a limited age span (41-58 years) in the REBUS study, age was found to be of significant importance in relation to vibration and warmth perception thresholds on the foot. An increase in vibration and thermal thresholds with age, especially on the foot, is in accordance with previous reports, and has been explained as a distal-proximal ageing process affecting all modalities of sensory function (Bartlett et al., 1998; Skov et al., 1998b). Pain thresholds were often found to increase with age in the present study, but the relations were not significant except for the pressure pain threshold on the trapezius and the heat pain threshold, in women. According to the hypothesis of a distal-proximal degenerative age process, an elevation of pain thresholds probably would have been more pronounced on the foot. However, the pressure pain threshold measured on the frontal surface of the right tibia showed a smaller age-dependent increase compared to more proximal test locations.

Body height was positively related to vibration and thermal thresholds on the foot, but not on the hand, a finding in accordance with results from other studies (Bartlett et al., 1998; Gerr et al., 1994). Body height was also positively correlated with pain thresholds in women, but not in men. Body dimensions are related to the density of receptors in the skin (Stevens & Choo, 1998), thereby probably explaining the increased pain thresholds among tall subjects, but there is no known biological reason why this relationship should differ between men and women.

Local skin temperature was inversely related to cold thresholds (i.e. sensitivity to cold was higher among those with higher skin temperature) on the foot in both genders, but not to any other threshold. This has not been reported in other studies. On the contrary, slightly poorer vibrotactile and temperature thresholds was found in subjects with higher skin temperature in a study by Gerr and Letz (Gerr & Letz, 1994). Bartlett et al (1998) suggested that the skin temperature on the hand was not important in relation to vibration and thermal thresholds. However, the relation between thresholds on the foot and the skin temperature on the foot was not reported (Bartlett et al., 1998).

In the present study smoking was found to be positively related to pressure pain thresholds in men (i.e. male smokers were less sensitive to pressure pain), but surprisingly, negatively related to pressure pain thresholds in women (i.e. female smokers were more sensitive to pressure pain). Literature reports on the influence of smoking status on perception thresholds are sparse, except for a finding of slightly and mostly non-significantly elevated vibrotactile and thermal thresholds in a study of Vietnam veterans (Gerr & Letz, 1994).

Musculoskeletal symptoms during the last seven days prior to examination showed a negative association to pressure pain thresholds in women (i.e. the sensitivity to pressure pain was increased in among women with symptoms), but not in men. Lower pressure pain thresholds have been explained as an indicator of unspecified tissue damage and are often correlated with symptoms, but seldom with clinical findings (Byström et al., 1995; Takala, 1990). Musculoskeletal symptoms in the hand/wrist area showed a positive association with the vibration threshold on the hand in women, but not in men (i.e. the sensitivity to vibrations was decreased in women with symptoms). In women there was also a tendency to increased sensitivity to vibrations on the hand in relation to PWL, indicating that vibration thresholds in women might be related to variables not included in the PWL score, e.g. repetitive hand intensive work. However, in an additional multivariate analysis using repetitive hand work instead of PWL score, no such relation was found in the women of this study.

Impact of physical work load

There have been only sparse reports in the literature concerning physical capacity in relation to previous physical work loads, and the findings have been mostly related to the current work situation. Training effects might be attained within some weeks or months, but negative effects due to high strain and frequent overload might possibly take more time to develop. This emphasises the need for longitudinal studies of the associations between musculoskeletal capacity and physical work loads (De Zwart et al., 1995). In the present study physical capacity was measured only at the end of follow-up and intra-individual changes in strength over time could therefore not be evaluated, hens the possibility of selection into or away from certain kinds of jobs on the basis of physical capacity cannot be ruled out. Health selection of individuals both into and out of high physically demanding jobs is well known. For example, young men in physically demanding jobs have been found to be stronger than other men, suggesting a preferential selection into heavy jobs (Era, 1992), and women with health problems working in physically demanding jobs change more often than other women to less skilled and less physically demanding jobs (Östlin, 1988). In any situation where an accumulation of healthier and stronger people in physically demanding jobs occurs, true adverse effects on physical capacity might be underestimated in a cross-sectional study. Nevertheless, several studies with a cross-sectional design, in addition to the results of study IV have shown a lower capacity in older age groups with high physical work loads (Era, 1992; Nygård et al., 1988a; Nygård et al., 1988b; Schibye & Christensen, 1997). In a longitudinal study of older municipal workers in Finland, a marked decline in capacity was observed during a four-year follow-up period in both men and women, but this was unrelated to the physical work content (Nygård et al., 1991).

In study IV a varying pattern was observed regarding the associations between physical capacity and physical work load during different exposure periods back in time. In concordance with the primary hypothesis, some associations between high previous physical work loads and low trunk flexion strength, low squatting endurance and low aerobic power were found, mainly among women with long-lasting high physical demands at work. The conclusion that long-lasting physically heavy work has an adverse effect was further strengthened by the increase in point estimates with increasing duration of physically heavy work. This suggests a cumulative effect of physical work load on capacity.

A finding that decreased trunk flexion strength is related to physical work load only in women has not previously been reported in the literature. Decreased trunk flexion strength has been found especially in back patients (Thorstensson et al., 1982) and among men in concrete reinforcement work to be related to previous lumbago episodes, but not to accumulated exposure (Nummi et al., 1978). There are other possible explanations for the restriction of the above relationship to women, e.g. low abdominal muscle strength in women due to interacting effects of pregnancy, in combination with adverse effects of long-lasting high physical work load. Decreased abdominal strength has been related to pregnancy in a follow-up study among randomly selected subjects, but no relation to job title was found (Andersen et al., 1994). However, the latter study was performed on younger subjects (23-27 years) with a low accumulated physical work load in comparison with the subjects of the present study. A reduced squatting capacity in individuals with a high physical work load might be due to osteoarthrosis of the hip and knee joints, as has been described in groups with long-lasting high physical exposure (Vingård et al., 1991a; Vingård et al., 1991b). Low aerobic power in groups with physically demanding work during their entire working life has also been demonstrated earlier, but only among in (Nygård et al., 1994), which is in contrast to the present study results.

An association in the opposite direction to the primary hypothesis was found for hand grip strength in both men and women and for weight-lifting endurance in men, possibly indicating a training effect of high physical work load on the upper extremities. This was further supported by the post hoc analyses, although only in the men. The restriction of training effects to the upper extremities is difficult to explain. It is possible that physically demanding jobs of today might provide sufficient combinations of level, duration and frequency of loads to achieve training effects on the upper extremity muscles but not on other muscle groups. In a Swedish study of mixed occupational groups, no significant association between life-time exposure to physical heavy work and isometric muscle strength was found (Nygård et al., 1994). That study however, concerned the relation between physical capacity and accumulated life-time work load, and not average annual work load, with the possibility that high accumulated loads also occurred in jobs with low exposure levels.

The sensory thresholds studied were chosen in order to cover different sensory modalities and different types of fibres in afferent cutaneous nerves. One aim was to explore the possible negative influence of physical work load on sensory function. However, only a weak indication of decreased warmth perception on the hand in relation to PWL was found in the men. A possible explanation is that impaired sensory function is primarily related to chemical/toxic exposures acting both on free nerve endings in the skin and on other parts of the sensory pathway, and less related to physical exposures acting mainly on free nerve endings and end-organs/receptors in the skin. Another explanation might be that influences on sensory thresholds by physical work loads cannot be clearly demonstrated in population studies on account of too small contrasts and frequent covariation between several possible adverse exposures, as has been pointed out in earlier studies (Halonen, 1986; Lundström et al., 1999). This possibility is further supported by results from studies of subjects with high vibration exposure, which have shown more obvious influence on temperature and vibration thresholds (Ekenvall et al., 1989; Virokannas et al., 1995).

In study V physical work load (PWL score) was positively related to pressure pain threshold in men, but not in women. Reduced sensitivity to pressure pain on the hands in subjects working in heavy physical occupations could perhaps be related to dermal thickening on the hands, but Byström et al (1995) found no difference in pressure pain thresholds between a group of automobile assembly line workers and a general population sample (Byström et al., 1995). In the present study higher pressure thresholds in men with a high physical work load were seen on all parts of the body, and not only on the hands, and dermal thickening is thus a less likely explanation. However, little has been reported on this topic in the literature, except for one study, in which no relation between the presence of calluses and sensory thresholds was found (Gelber et al., 1995).

Conclusions

- Questionnaire-based information on physical work loads in the past seems to be reliable enough to be used at a rough level in epidemiological studies on general population groups.
- Questionnaire-based information was found to capture more variation in physical work loads, especially among those remaining in the same job for long periods, compared to exposure assessment based on job titles.
- Increasing fractions of white-collar work and decreasing physical loads were found among men during the time period between 1970 and 1993. But among women the loads were unchanged or increased and the fraction of blue-collar work increased.
- Indications of a possible weakening/ or wearing effect on the trunk and the lower extremities were observed, especially among women reporting high physical work loads.
- Indications of a possible maintaining and/or training effect of the upper extremities among those reporting high physical work loads, were also found.
- Pressure pain thresholds were related to isometric muscle strength, but aerobic power was not.

Summary

Margareta Torgén. *Physical loads and aspects of physical performance in middle-aged men and women.* Arbete och Hälsa 1999:14.

This investigation aimed at a description of different aspects of physical loads during a 24 year follow-up (1970-1993) in 484 men and women born between 1935 and 1952, in relation to different aspects of physical performance, as measured at follow-up. The subjects were originally recruited in 1969 from the Stockholm county general population. Quality aspects of questionnaire data on physical loads in the past were also examined.

Test-retest reliability, for physical activities at work exceeded that for leisure time and physical training activities, and correlation did not differ markedly between past and present activities. No distinct influence of gender or low back health on one-year reproducibility was found. Six-year reproducibility, showed highest values for the proportion of the working day spent sitting and for perceived general exertion and the lowest values for trunk and neck flexion.

Validity of questionnaire responses on physical work loads six year back in time in relation to work-place measurements performed six years ago at these work-places showed the highest values for items sitting and repetitive work and the lowest, unacceptable values for head rotation and neck flexion. Misclassification of exposure did not appear to be differential with regard to musculoskeletal symptom status, as judged by calculated risk estimates.

During the follow-up period (1970 to 1993) the proportion of subjects in blue-collar occupations and the physical work loads decreased among men, but both increased among women. Physical work loads were in general higher among men than among women at younger ages (below 30 years), but the difference was smaller at higher ages. Expert evaluations of the musculoskeletal load showed a pattern similar to that of self-reported work loads.

Consistently with previous reports, but mainly among the women, prolonged physically heavy demands showed associations with low trunk flexion strength, squatting endurance and aerobic power. In contrast, low isometric hand grip strength and low weight-lifting endurance were seldom seen among those with high physical work loads, indicating a possible maintaining or training effect on the hand/arm/shoulder muscle groups.

A consistent covariation between muscle strength and pain thresholds was found in both men and women. Increased sensory thresholds with age were observed even within the limited age span of this study. The sensory thresholds showed only slight covariation with physical work load.

Keywords: physical work load, age, gender, muscle strength, aerobic power, sensory threshold, epidemiology, questionnaire, reproducibility, validity

Sammanfattning (Summary in Swedish)

Margareta Torgén. *Physical loads and aspects of physical performance in middle-aged men and women.* Arbete och Hälsa 1999:14.

Syftet med denna undersökning var att beskriva fysisk belastning under en 24-års uppföljningsperiod (1970-1993) i relation till olika former av fysisk prestationsförmåga, vilka undersöktes vid uppföljningstillfället 1993. Dessutom undersöktes kvalitetaspekter på frågeformulärsdata om retrospektiv fysisk belastning i arbetet. Studien innefattar 484 män och kvinnor födda 1935-1954, slumpmässigt valda från Stockholms läns befolkning i samband med REBUS-undersökningen 1969.

Test-retest reproducerbarhet (två veckors intervall), visade bättre resultat för frågor om fysisk belastning i yrkesarbete jämfört med frågor om belastning på fritiden. Resultaten var ungefär lika för nuvarande belastningar och belastningar bakåt i tiden. Ett-års reproducerbarhet visade ingen säker skillnad mellan män och kvinnor och ingen säker inverkan av ländryggsbesvär. Sex-års reproducerbarhet visade bästa resultat för frågor om sittande arbete och om upplevd allmän ansträngning, och lägsta resultat för frågor om arbete med framåtböjd nacke och framåtböjd bål.

Validitet av frågeformulärsdata om fysisk arbetsbelastning sex år bakåt i tiden i relation till arbetsplatsmätningar genomförda för sex år sedan, visade bäst resultat för frågor om sittande arbete och repetetivt arbete och sämst resultat för frågor avseende rotation och framåtböjning av huvudet. Klassificering av fysisk arbetsbelastning med frågeformulär var inte relaterat förekomst av muskuloskeletala besvär.

Under uppföljningsperioden 1970-1993 minskade andelen sysselsatta i arbetaryrken liksom den fysiska belastningen bland männen, men steg bland kvinnorna. Fysisk belastning i arbetet var högre bland yngre män jämfört med yngre kvinnor (under 30 år), men skillnaden utjämnades vid högre åldrar. Expertbedömning av fysisk belastning i arbetet baserat på yrkestitlar överensstämde med den belastning som studiepersonerna angav med frågeformulär.

Mångårig (10-20 år) hög fysisk belastning i arbetet visade särskilt bland kvinnorna samband med låg muskelstyrka i bålens framåtböjare, låg uthållighet vid huksittning och låg kondition. Däremot var låg styrka i handgrepp och låg styrka i armarnas och skuldrans muskler mindre vanligt bland personer med fysisk hög belastning i arbetet, talande för en möjlig träningseffekt av yrkesarbete på dessa muskelgrupper.

Vid undersökning av känslighet i huden för olika typer av sensoriska stimuli sågs tydligt samband mellan hög muskelstyrka och låg känslighet för trycksmärta. Minskad sensorisk känslighet med åldern framkom trots studiens begränsade åldersintervall (41-58 år). Påverkan på känseluppfattning i huden av fysisk belastning i yrkesarbete framkom endast i liten utsträckning.

Nyckelord: fysisk belastning, ålder, kön, muskelstyrka, kondition, känseltrösklar, epidemiologi, frågeformulär, reproducerbarhet, validitet

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References

Ainsworth B, Haskell W, Leon A, Jacobs jr D, Montoye J & Paffenbarger R (1993) Compendium of physical activities: classification of energy costs of human physical activities. *Med Sci Sports Exerc,* 25(1), 71-80.

Alaranta H, Heikki H, Heliövaara M, Soukka A & Harju R (1994) Non-dynamometric trunk performance tests: Reliability and normative data. *Scand J Rehab Med,* 26, 211-215.

Alaranta H, Soukka A, Harju R & Heliövaara M (1990) *Improvement of the diagnostics of musculoskeletal diseases: measuring the capacity of back and neck and shoulders in the occupational health service (in Finnish with summary in English).* , Helsinki: Rehabilitation Unit of The Invalid Foundation.

Aminoff T, Smolander J, Korhonen O & 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 & Louhevaara V (1999) Physiological strain during kitchen work in relation to maximal and task-specific values. *Ergonomics,* 42(4), 584-592.

Andersen L & Haraldsdóttir J (1994) Changes in physical activity, maximal isometric strength and maximal oxygen uptake from late teenage to adulthood: an eight-year follow-up study of adolescents in Denmark. *Scand J Med Sci Sports,* 4, 19-25.

Andrew M, Bhambhani Y & Wessel J (1998) Physiological and perceptual responses during household activities performed by healthy women. *Am J Occup Ther,* 52(7), 556-562.

Aoyagi Y & Shephard RJ (1992) Ageing and muscle function. *Sports Med,* 14(Dec 6), 376-96.

Armstrong B, White E & Saracci R (1992) Chap.4: Validity and reliability studies. *Monographs in Epidemiology and Biostatistics: Principles of Exposure Measurement in Epidemiology.* Vol. 21. Pp 78-114, : Oxford University Press, Oxford.

Armstrong T, Buckle P, Fine L, Hagberg M, Jonsson B, Kilbom Å, Kuorinka I, Silverstein B, Sjøgaard G & Viikari-Juntura E (1993) A conceptual model for work-related neck and upper-limb musculoskeletal disorders. *Scand J Work Environ Health,* 19, 73-84.

Aronsson G, Kilbom Å & editors (1996) *Arbete efter 45. Historiska, psykologiska och fysiologiska perspektiv på äldre i arbetslivet (Work after 45. Historical, psychological, and physiological perspectives on older workers in working life).* Fakta från Arbetslivsinstitutet. Solna: Arbetslivsinstitutet.

Asmussen E & Hebøll-Nielsen K (1961) Isometric muscle strength of adult men and women. Danish National Association for Infantile Paralysis. *Dan Nat Assoc for Infantile Paralysis.,* Comm. No.11.

Barnekow-Bergkvist M, Hedberg G, Janlert U & Jansson E (1996) Development of muscular endurance and strength from adolescence to adulthood and level of physical capacity in men and women at the age of 34 years. *Scand J Med Sci Sports,* 6, 145-155.

Bartlett G, Stewart J, Tamblyn R & Abrahamowicz M (1998) Normal distributions of thermal and vibration sensory thresholds. *Muscle Nerve*(March), 367-374.

Bemben GM, Massey BH, Bemben DA, Misner JE & Boileau RA (1991) Isometric muscle force production as a function of age in healthy 20- to 74- yr-old men. *Med Sci Sports Exerc,* 23(11), 1302-1310.

Bemben M (1998) Age-related alterations in muscular endurance. *Sports Med,* 25(4), 259-269.

Bergkvist M, Hedberg G & Rahm M (1992) Assessment of physical capacity. An evaluation of strength, flexibility and coordination tests. (In Swedish with abstract in English). *Arbete och Hälsa,* 1992:5, 1-19.

Bernard BP editor (1997) *Musculoskeletal disorders and workplace factors. A critical review of epidemiological evidence for work-related musculoskeletal disorders of the neck, upper extremity, and low back.* (Second printing ed.) DHHS (NIOSH) publication No. 97-141. Cincinnati: U.S. Department of Health and Human Services, NIOSH.

Bildt Thorbjörnsson C (1999) *A quarter century perspective on low back pain- A longitudinal study. Arbete och Hälsa 1999:9.* Doctoral thesis, Karolinska Institute. Stockholm: Department of Clinical Neuroscience.

Björkstén M, Boquist B, Talbäck M & Edling C (1996) Neck and shoulder ailments in a group of female industrial workers with monotonous work. *Ann Occup Hyg,* 40(6), 661-673.

Blair S, Dowda M, Pate R, Kronenfeld J, Howe H, Parker G & et al (1991) Reliability of long-term recall of participation in physical activity by middle-aged men and women. *Am J Epidemiol,* 133(3), 266-275.

Blair S, Kohl H & Barlow;CE (1993) Physical activity, physical fitness,and all-cause mortality in women: do women need to be active? *J Am Coll Nutr,* 12(4), 368-371.

Blair S, Kohl H, Gordon N & Paffenberger RJ (1992) How much physical activity is good for health? *Annu Rev Public Health,* 13, 99-126.

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

Brulin C, Gerdle B, Granlund B, Höög J, Knutson A & Sundelin G (1998) Physical and psychosocial work-related risk factors associated with musculoskeletal symptoms among home care personnel. *Scand J Caring Sci,* 12, 104-110.

Burdorf A (1995) Reducing random measurement error in assessing postural load on the back in epidemiological surveys. *Scand J Work Environ Health,* 21, 15-23.

Bygren LO (1974) Met and unmet needs for medical and social services. *Scand J Soc Med,* Supp 8, 1-135.

Byström S, Hall C, Welander T & Kilbom Å (1995) Clinical disorders and pressure-pain threshold of the forearm and hand among automobile assembly line workers. *J Hand Surg,* 20B(6), 782-790.

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

Carmines E & Zeller R (1979) Assessing reliability. In: Carmines E & Zeller R eds. *Reliability and Validity Assessment.* Vol. 17. Pp 37-57, , Los Angeles: Beverly Hills Sage University.

Chasan-Taber S, Rimm E, Stampfer M, Spiegelman D, Colditz G, Giovannucci E & et.al. (1996) Reproducibility and validity of a self-administered physical activity questionnaire for male health professionals. *Epidemiology,* 7(1), 81-86.

De Looze M, Toussaint H, Ensink J, Mangnus C & van der Beek A (1994) The validity of visual observation to assess posture in a laboratory-simulated, manual material handling task. *Ergonomics,* 37(8), 1335-1343.

De Zwart B, Broersen J, Van der Beek A, Frings-Dresen M & Van Dijk F (1997) Occupational classification according to work demands: an evaluation study. *Int J Occup Med Environ Health,* 10(3), 283-295.

De Zwart BCH, Frings-Dresen MHW & Van Dijk FJH (1995) Physical workload and the aging worker: a review of the literature. *Int Arch Occup Environ Health,* 68, 1-12.

Dorfman L & Robinson L (1997) AAEM Minimonograph #47: Normative data in electrodiagnostic medicine. *Muscle Nerve,* 20, 4-14.

Du Bois D & Du Bois E (1916) Clinical calorimetry, tenth paper: A formula to estimate the approximate surface area if height and weight be known. *Arch Intern Med,* 17, 863-871.

Ekenvall L, Gemne G & Tegner R (1989) Correspondence between neurological symptoms and outcome of quantitative sensory testing in the hand-arm vibration syndrome. *Br J Ind Med,* 46, 570-574.

Engström L, Ekblom B, Forsberg A, Koch M & Seger J (1993) *Livsstil-Prestation-Hälsa, LIV 90. Rapport 1: Motionsvanor, fysisk prestationsförmåga och hälsotillstånd bland svenska kvinnor och män i åldrarna 20-65 år (Lifestyle-Performance-Health: Physical activity habits, fitness and health among Swedish women and men at the ages of 20-65).* . Farsta: Idrottens förlag.

Era P (1992) Determinants of isometric muscle strength in men of different ages. *Eur J Appl Physiol,* 64, 84-91.

Era P, Jokela J, Suominen H & Heikkinen E (1986) Correlations of vibrotactile thresholds in men of different ages. *Acta Neurol Scand,* 74, 210-217.

Estlander A, Takala E & Viikari-Juntura E (1998) Do psychological factors predict changes in musculoskeletal pain? *JOEM,* 40(5), 445-453.

Falkner K, Trevisan M & McCann S (1999) Reliability of recall of physical activity in the distant past. *Am J Epidemiol,* 150(2), 195-205.

Feine J, Bushnell M, Miron D & Duncan G (1991) Sex differences in the perception of noxious heat stimuli. *Pain,* 44, 255-262.

Fillingim R, Maixner W, Kincaid S & Silva S (1998) Sex differences in temporal summation but not sensory-discriminative processing of thermal pain. *Pain,* 75, 121-127.

Fleiss J (1981) The measurement of interrater agreement. In: Fleiss J ed. *Statistical methods for rates and proportions.* Vol. Chap 13. Pp 212-236, 2 ed, New York: John Wiley & Sons.

Fleiss J & Cohen J (1973) The equivalence of weighted kappa and the intraclass correlation coefficient as measures of reliability. *Educ Psychol Meas,* 33, 613-619.

Ford ES, Merritt RK, Heath GW, Powell KE, Washburn RA, Kriska A & Haile G (1991) Physical activity behaviors in lower and higher socioeconomic populations. *Am J Epidemiol,* 133(12), 1246-1256.

Fransson-Hall C, Gloria R, Kilbom Å, Winkel J, Karlqvist L, Wiktorin C & Stockholm Music 1 Study Group (1995) A portable ergonomic observation method (PEO) for computerized on-line recording of postures and manual handling. *Appl Ergon,* 26(2), 93-100.

Fransson-Hall C & Kilbom Å (1993) Sensitivity of the hand to surface pressure. *Appl Ergonom,* 24(3), 181-189.

Friedenreich C, Courneya K & Bryant H (1998) The lifetime total physical activity questionnaire: development and reliability. *Med Sci Sports Exerc,* 30(2), 266-274.

Frontera W, Hughes V, Lutz K & Evans W (1991) A cross-sectional study of muscle strength and mass in 45- to 78-yr-old men and women. *J Appl Physiol,* 71(2), 644-650.

Gelber D, Pfeifer M, Broadstone V, Munster E, Peterson M, Arezzo J & et. al. (1995) Components of variance for vibratory and thermal threshold testing in normal and diabetic subjects. *J Diabetes Compl,* 9, 170-176.

Gerr F & Letz R (1994) Covariates of human peripheral nerve function: II. Vibrotactile and thermal thresholds. *Neurotox Teratol,* 16(1), 105-112.

Gibbons L, Battié M & Videman T (1995) Changes in occupational physical loading during the lifetimes of Finnish men. *Scand J Work Environ Health,* 21, 208-214.

Goldberg J & Lindblom U (1979) Standard method of determining vibratory perception thresholds for diagnosis and screening in neurological investigation. *J Neurol Neurosurg Psychiat,* 42, 793-803.

Hagberg M (1981) Work load and fatigue in repetitive arm elevations. *Ergonomics,* 24, 543-555.

Hagberg M (1992) Exposure variables in ergonomic epidemiology. *Am J Ind Med,* 21, 91-100.

Hagberg M, Goldie I, Hogstedt C, Kilbom Å, Ahlbom A, Ekholm J & et.al. (1990) Plan and operation of the Stockholm MUSIC I study. Prevention of musculoskeletal disorders.

23rd International Congress on Occupational Health of the International Commission on Occupational Health, ICO 1990, Sept 22-28, Montreal, Canada.

Hall E (1992) Double exposure: the combined impact of the home and work environments on psychosomatic strain in Swedish women and men. *Int J Health Serv,* 22(2), 239-260.

Halonen P (1986) Quantitative vibration perception thresholds in healthy subjects of working age. *Eur J Appl Physiol,* 54, 647-655.

Harju R, Alaranta H, Soukka A & Heliövaara M (1991) Developing non-dynamometric tests for measurement of performance capacity. World Federation for Physical Therapy. 11th Int Congress, London.

Helmrich S (1994) Prevention of non-insulin-dependent diabetes mellitus with physical activity. *Med Sci Sports Exerc,* 26(7), 824-830.

Heyward V, Joannes-Ellis S & Romer J (1986) Gender differences in strength. *Res Quart Exc Sport,* 57(2), 154-159.

Hogan J (1991) Structure of physical performance in occupational tasks. *J Appl Psychol,* 76(4), 495-507.

Hoppin J, Tolbert P, Flagg E, Blair A & Zahm S (1998) Use of a life events calendar approach to elicit occupational history from farmers. *Am J Ind Med,* 34, 470-476.

Hortobagyi T, Zheng D, Weidner M, Lambert N, Westbrook S & Houmard J (1995) The influence of aging on muscle strength and muscle fiber characteristics with special reference to eccentric strength. *J Gerontol A Biol Sci Med Sci,* 50(6), B399-406.

Huang Y, Macera C, Blair S, Brill P, Kohl 3rd H & Kronenfeld J (1998) Physical fitness, physical activity, and functional limitation in adults aged 40 and older. *Med Sci Sports Exerc,* 30(9), 1430-1435.

Hughes R, Silverstein B & Evanoff B (1997) Risk factors for work-related musculoskeletal disorders in an aluminium smelter. *Am J Ind Med,* 32(1), 66-75.

Ilmarinen J (1992a) Job design for the aged with regard to decline in their maximal aerobic capacity: Part 1- Guidelines for the practitioner. *Int J Ind Erg,* 10, 53-63.

Ilmarinen J (1992b) Job design for the aged with regard to decline in their maximal aerobic capacity: Part 2- The scientific basis for the guide. *Int J Ind Erg,* 10, 65-77.

Ilmarinen J, Louhevara V, Korhonen O, Nygård C-H, Hakola T & Suvanta 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 & Landau K (1991b) Classification of municipal occupations. *Scand J Work Environ Health,* 17(Suppl. 1), 12-29.

International Labor Office (1958) *Nordic Occupational Classification based on International standard Classification of Occupations.* . Geneva: ILO.

Izquierdo M, Aguado X, Gonzalez R, Lopez J & Hakkinen K (1999) Maximal and explosive force production capacity and balance performance in men of different ages. *Eur J Appl Physiol,* 79(3), 260-267.

Jackson A (1994) Chapter 3: pre-employment physical evaluation. *Exerc Sports Sci Rev,* 53-90.

Jackson A, Beard E, Wier L, Ross R, Stuteville J & Blair S (1995) Changes in aerobic power of men, aged 25-70 yr. *Med Sci Sports Exerc,* 27(1), 113-120.

Jackson A, Wier L, Ayers G, Beard E, Stuteville J & Blair S (1996) Changes in aerobic power of women, aged 20-64 yr. *Med Sci Sports Exerc,* 28(7), 884-891.

Jensen K (1990) Chap 9: Quantification of tenderness by palpation and use of pressure algometers. In: Fricton J & Awad E eds. *Adv Pain Res Therapy.* Vol. 17. Pp 165-181, , New York: Raven Press Ltd.

Karlqvist L, Winkel J & Wiktorin C (1994) Direct measurements and systematic observations of physical workload among medical secretaries, furniture removers and male and female reference populations. *App Ergon,* 25(5), 319-326.

Kemmlert K (1995) A method assigned for the identification of ergonomic hazards - PLIBEL. *Appl Ergon,* 26(3), 199-211.

Kilbom Å (1988) Isometric strength and occupational muscle disorders. *Eur J Appl Physiol,* 57, 322-326.

Kilbom Å (1994) Assessment of physical exposure in relation to work-related musculoskeletal disorders - what information can be obtained from systematic observations? *Scand J Work Environ Health,* 20(Special issue), 30-45.

Kilbom Å, Armstrong T, Bucle P, Fine L, Hagberg M, Haring-Sweeney M & et.al. (1996a) Musculoskeletal disorders: work-related risk factors and prevention. *Int J Occup Environ Health,* 2(3), 239-246.

Kilbom Å, Hultgren D, Aronsson G, Hallsten L & Torgén M (1998) *Utvärdering av forskningsprogrammet "Arbete Efter 45" (Evaluation of "Work After 45" - a research programme).* Arbetslivsrapport 1998:7 66p, Solna: Arbetslivsinstitutet.

Kilbom Å & Persson J (1981) Circulatory response to static muscle contractions in three different muscle groups. *Clin Physiol,* 1, 215-225.

Kilbom Å & Torgén M (1996b) Fysisk förmåga och hälsa bland äldre i yrkeslivet (Physical capacity and health among older people in the working life). In: Aronsson G & Kilbom Å eds. *Arbete efter 45. Historiska, psykologiska och fysiologiska perspektiv på äldre i arbetslivet (Work after 45. Historical, psychological, and physiological perspectives on older workers in working life).* Pp 103-133, , Solna: National Institute for Working Life.

Kilbom Å, Wigaeus-Hjelm E, Käll C & Stockholm MUSIC I Study Group (1993) Validering av submaximalt cykelergometertest (Validation of a sub-maximal ergometer test). In: Hagberg M & Hogstedt C eds. *Data från en tvärsnittsundersökning av ergonomisk och psykosocial exponering samt sjuklighet och funktion i rörelseorganen (Data from a cross-sectional study of ergonomic and psychosocial exposure, and disease and musculoskeletal function).* Vol. 1. Pp 296-306, , Spånga: MUSIC Books.

Kilbom Å, Wigaeus-Hjelm E & Stockholm MUSIC I Study Group (1991) Fysisk arbetsförmåga i Stockholmsundersökningen 1 (Physical capacity in Stockholmsundersökningen 1). In: Hagberg M & Hogstedt C eds. *Data från en tvärsnittsundersökning av ergonomisk och psykosocial exponering samt sjuklighet och funktion i rörelseorganen (Data from a cross-sectional study of ergonomic and psychosocial exposure, and disease and musculoskeletal function).* Vol. 1. Pp 258-266, , Spånga: MUSIC Books.

Kriska A, Black Sandler R, Cauley J, LaPorte R, Holm D & Pambianco G (1988) The assessment of historical physical activity and its relation to adult bone parameters. *Am J Epidemiol,* 127(No5), 1053-1061.

Kuorinka I, Jonsson B, Jørgensen K, Kilbom Å, Sejersted O & Vinterberg H (1990) *Arbetsrelaterade sjukdomar i rörelseorganen - förekomst, orsaker och förebyggande. En kunskaps- och problemöversikt. (Work-related disorders of the musculoskeletal system - occurance, causes and prevention. A review of knowledge and problems).* (Vol. 1990:6) Nordiska Ministerrådet. Køpenhavn: Nordiska Ministerrådet.

Laforest S, St-Pierre D, Cyr J & Gayton D (1990) Effects of age and regular exercise on muscle strength and endurance. *Eur J Appl Physiol,* 60, 104-111.

Laubach L (1976) Comparative muscular strength of men and women: a review of the literature. *Aviat Space Environ Med,* 47(5), 534-542.

Lautenbacher S & Strian F (1991) Sex differences in pain and thermal sensitivity: The role of body size. *Perc Psychophys,* 50(2), 179-183.

Lemaitre R, Siscovick D, Ragghunathan T, Weinmann S, Arbogast P & Lin D (1999) Leisure-time physical activity and the risk of primary cardiac arrest. *Arch Intern Med,* 159(7), 686-690.

Li G & Buckle P (1999) Current techniques for assessing physical exposure to work-related musculoskeletal risks, with emphasis on posture-based methods. *Ergonomics,* 42(5), 674-695.

Luff A (1998) Age-associated changes in the innervation of muscle fibers and changes in the mechanical properties of motor units. *Ann N Y Acad Sci,* 20(854), 92-101.

Lundberg U (1996) Influence of paid and unpaid work on psychophysiological stress responses of men and women. *J Occup Health Psychol,* 1(2), 117-130.

Lundström R, Nilsson T, Burström L & Hagberg M (1999) Exposure-response relationship between hand-arm vibration and vibrotactile perception sensitivity. *Am J Ind Med,* 35, 456-464.

Luoma K, Riihimäki H, Raininko R, Luukkonen R, Lamminen A & Viikari-Juntura E (1998) Lumbar disc degeneration in relation to occupation. *Scand J Work Environ Health,* 24(5), 358-366.

Lusa S, Louhevaara V & Kinnunen K (1994) Are the job demands on physical work capacity equal for young and aging fire fighters? *J Occup Med,* 36, 70-74.

McAtammy L & Corlett N (1993) RULA: a survey method for the investigation of work-related upper limb disorders. *Appl Ergon,* 24(2), 91-99.

McCarter RJM (1990) Age-related changes in skeletal muscle function. *Aging,* 2(1), 27-38.

Miettinen M & Louhevaara V (1994) Job demands, physical fitness, work ability, and age of vehicle inspectors. *Int J Ind Ergon,* 13, 337-342.

Miller A, MacDougall J, Tarnopolsky M & Sale D (1993) Gender differences in strength and muscle fiber characteristics. *Eur J Appl Physiol,* 66(3), 254-262.

NIOSH (1981) *Work Practices Guide for Manual Lifting.* . Washington: Washington: U.S. Department of Health and Human Services.

Nordström D, Vierkant R, Layde P & Smith M (1998) Comparison of self-reported and expert-observated physical activities at work in a general population. *Am J Ind Med,* 34, 29-35.

Nummi J, Järvinen T, Stambej U & Wickström G (1978) Diminished dynamic performance capacity of back and abdominal muscles in concrete reinforcement workers. *Scand J Work Environ Health,* 4(suppl1), 39-46.

Nygård C, Kilbom Å, Wigaeus Hjelm E, Winkel J & Stockholm MUSIC 1 Study Group (1994) Life-time occupational exposure to heavy work and individual physical capacity. *Int J Ind Erg,* 14, 365-372.

Nygård C-H, Huuhtanen P, Tuomi K & Martikainen R (1997) Percived work changes between 1981 and 1992 among aging workers in Finland. *Scand J Work Environ Health,* 23 suppl 1, 12-19.

Nygård C-H, Luopajärvi T, Cedercreutz G & Ilmarinen J (1987) Musculoskeletal capacity of employees aged 44 to 58 years in physical, mental and mixed types of work. *Eur J Appl Physiol,* 56, 555-561.

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

Nygård C-H, Luopajärvi T & 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, Luopajärvi T, Suurnäkki T & Ilmarinen J (1988b) Muscle strength and muscle endurance of middle-aged woman and men associated to type, duration and intensity of muscular load at work. *Int Arch Occup Environ Health,* 60, 291-297.

Nygård C-H, Suurnäkki T, Peltomaa T & Ilmarinen J (1995) Objectively assessed job demands among elderly employees in 1981 and 1993. In: Kumasoro M ed. *The paths to productive aging.* Pp 325-330, , London: Taylor and Francis.

Ogawa T, Spina R, Martin III W, Kohrt W, Schechtman K, Holloszy J & et.al. (1992) Effects of aging, sex and physical training on cardiovascular responses to exercise. *Circulation,* 86(2), 494-503.

Oja P, Louhevaara V & Korhonen O (1977) Age and sex as determinants of the relative aerobic strain of nonmotorized mail delivery. *Scand J Work Environ Health,* 3, 225-233.

Paulson P, Minoshima S, Morrow T & Casey K (1998) Gender differences in pain perception and patterns of cerebral activation during noxious heat stimulation in humans. *Pain,* 76, 223-229.

Pope D, Silman A, Cherry N, Pritchard C & Macfarlane G (1998) Validity of a self-completed questionnaire measuring the physical demands of work. *Scand J Work Environ Health,* 24(5), 376-385.

Porter MM, Vandervoort AA & Lexell J (1995) Aging of human muscle: structure, function and adaptability. *Scand J Med Sci Sports,* 5, 129-142.

Punnett L (1998) Ergonomic stressors and upper extremity disorders in vehicle manufacturing: cross sectional exposure-response trends. *Occup Environ Med,* 55, 414-420.

Punnett L, Fine L, Keyserling WM, Herrin G & Chaffin DB (1991) Back disorders and nonneutral trunk postures of automobile assembly workers. *Scand J Work Environ Health,* 17, 337-346.

Rantanen T, Parkatti T & Heikkinen E (1992) Muscle strength according to level of physical exercise and educational background in middle-aged women in Finland. *Eur J Appl Physiol,* 65, 507-512.

Reid J, Costigan P & Comrie W (1987) Prediction of trunk muscle areas and monent arms by use of anthropometric measures. *Spine,* 12(3), 273-275.

Roeykens J, Rogers R, Meeusen R, Magnus L, Borms J & De Meirleir K (1998) Validity and reliability in a Flemish population of the WHO-MONICA optional study of physical activity questionnaire. *Med Sci Sports Exerc,* 30(7), 1071-1075.

Rohmert W (1984) Das Belastungs-Beanspruchungs-Konzept. *Zeitschrift fur Arbeitswissenschaft,* 38, 193-200.

Romert W & Landau K (1983) *A new technique for job analysis.* . London: Taylor and Francis.

Rutenfranz J, Ilmarinen J, Klimmer F & Kyllian H (1990) Work load and demanded physical performance capacity under different industrial working conditions. In: Kanebo M ed. *Fitness for the Aged Disabled and Industrial Worker.* Pp 217-238, , Champaign: Human Kinetics Books.

SAS Institute (1985) *Inc. SAS user's guide: basics, version 5 ed. Cary, NC: Institute, Inc, 1985.* .

Schibye B & Christensen H (1997) The work load during waste collection and meat cutting among workers in different age groups. Work after 45? Conference. Stockholm 22-25 September 1996. *Arbete och Hälsa,* 1997;29(Vol 2), 272-278.

Selin K, Winkel J & group SMs (1994) Evaluation of two instruments for recording sitting and standing postures and number of foot steps. *Appl Erg,* 25(1), 41-46.

Shephard R (1997) Impact of regular physical activity on Age-associated changes in physiological systems. In: Shephard R ed. *Aging, physical activity, and health.* , Toronto: Human Kinetics.

Skov T, Deddens J, Petersen M & Endahl L (1998a) Prevalence proportion ratios: estimation and hypothesis testing. *Int J Epidemiol,* 27, 91-95.

Skov T, Steenland K & Deddens J (1998b) Effect of age and height on vibrotactile threshold among 1663 U.S. workers. *Am J Ind Med,* 34, 438-444.

Spirduso W (1980) Physical fitness, aging, and psychomotor speed: A review. *J Geron,* 35(6), 850-865.

Statistics Sweden SCB (1998) *LOUISE: A longitudinal data base for education, income, and employment.* . Stockholm.

Stevens J & Choo K (1998) Temperature sensitivity of the body surface over the life span. *Somatosensory and Motor Research,* 15(1), 13-28.

Stålberg E, Borges O, Ericsson M, Essén-Gustavsson B, Fawcett P, Nordesjö L-O, Nordgren B & Uhlin R (1989) The quadriceps femoris muscle in 20-70-year-old subjects: relationship between knee extension torque, electrophysiological parameters and muscle fiber characteristics. *Muscle & Nerve,* 12, 382-389.

Swerup C & Nilsson B (1987) Dependence of thermal thresholds in man on the rate of temperature change. *Acta Physiol Scand,* 131, 623-624.

Takala E & Viikari-Juntura E (1998) Prediction of neck and shoulder pain by functional tests. PREMUS-ISEOH ´98, 3rd International Scientific Conference on Prevention of Work-Related Musculoskeletal Disorders and 13th International Symposium on Epidemiology in Occupational Health, 21-25 September, Helsinki Finland.

Takala E-P (1990) Pressure pain threshold on upper trapezius and levator scapulae muscles. Repeatability and relation to subjective symptoms in a working population. *Scand J Rehab Med,* 22, 63-68.

Thompson M, Myers J & Kriebel D (1998) Prevalence odds ratio or prevalence ratio in the analysis of cross sectional data: what is to be done? *Occup Environ Med,* 55, 272-277.

Thorstensson A & Arvidson Å (1982) Trunk muscle strength and low back pain. *Scand J Rehab Med,* 14, 69-75.

Tuomi K, Ilmarinen J, Martikainen R, Alto L & Klockars M (1997) Aging, work, life-style and work ability among Finnish municipal workers in 1981-1992. *Scand J Work Environ Health*, 23 suppl 1, 58-65.

Walters T, Putz-Anderson V, Garg A & Fine L (1993) Revised NIOSH equation for the design and evaluation of manual lifting tasks. *Ergonomics,* 36(7), 749-776.

Van der Beek A & Frings-Dresen M (1998) Assessment of mechanical exposure in ergonomic epidemiology. *Occup Environ Med,* 55, 291-299.

Van der Beek A, Frings-Dresen M, Van Dijk F, Kemper H & Meijman T (1993) Loading and unloading by lorry drivers and musculoskeletal complaints. *Int J Ind Erg,* 12, 13-23.

Verdugo R & Ochoa J (1992) Quantitative somatosensory thermotest. A key method for functional evaluations of small calibre afferent channels. *Brain,* 115, 893-913.

WHO (1993) Aging and working capacity. *WHO Technical Report Series,* 835, 1-49.

Viikari-Juntura E, Rauas S, Martikainen R, Kuosma E, Riihimäki H, Takala E-P & Saarenmaa K (1996) Validity of self-reported physical work load in epidemiologic studies on musculoskeletal disorders. *Scand J Work Environ Health,* 22, 251-259.

Viitasalo JT, Era P, Leskinen A-L & Heikkinen E (1985) Muscular strength profiles and anthropometry in random samples of men aged 31-35, 51-55 and 71-75 years. *Ergonomics,* 28(11), 1563-1574.

Wiktorin C, Karlqvist L, Winkel J & Stockholm MUSIC I study group (1993) Validity of self-reported exposures to work postures and manual materials handling. *Scand J Work Environ Health,* 19(3), 208-14.

Wiktorin C, Wigaeus Hjelm E, Winkel J & Köster M (1996) Reproducibility of a questionnaire for assessment of physical load during work and leisure time. *J Occup Environ Med,* 38(2), 190-201.

Wiktorin C, Vingård E, Mortimer M, Pernold G, Wigaeus-Hjelm E, Kilbom Å & et. al. (1999) Interview versus questionnaire for assessing physical loads in the population-based MUSIC-Norrtälje study. *Am J Ind Med,* 35, 441-455.

Vingård E, Alfredsson L, Fellenius E & Hogstedt C (1992) Disability pensions due to musculo-skeletal disorders among men in heavy occupations. *Scand J Soc Med,* 20(1), 31-36.

Vingård E, Alfredsson L, Goldie I & Hogstedt C (1991a) Occupation and osteoarthrosis of the hip and knee: A register-based cohort study. *Int J Epidemiol,* 20(4), 1025-1031.

Vingård E, Alfredsson L, Hagberg M, Kilbom Å, Theorell T, Waldenström M & et.al. (1999) How much do current and past occupational physical and psychosocial factors explain of seeking care because of back pain in a working population? - results from the MUSIC - Norrtälje study. *Spine,* in press.

Vingård E, Alfredsson L & Malchau H (1998) Osteoarthrosis of the hip in women and its relationship to physical load from sports activities. *Am J Sports Med,* 26(1), 78-82.

Vingård E, Hogstedt C, Alfredsson L, Fellenius E & Köster M (1991b) Coxarthrosis and physical work load. *Scand J Work Environ Health,* 17, 104-109.

Winkel J & Mathiassen SE (1994) Assessment of physical work load in epidemiologic studies: concepts, issues and operational considerations. *Ergonomics,* 37(6), 979-988.

Virokannas H & Virokannas A (1995) Temperature and vibration perception thresholds in workers exposed to hand-arm vibration. *Cent Eur J Public Health,* 3(Suppl.), 66-69.

Zwiren L, Cureton K & Hutchinson P (1983) Comparison of circulatory responses to submaximal exercise in equally trained men and women. *Int J Sports Med,* 4, 255-259.

Åstrand I (1960) Aerobic work capacity in men and women with special reference to age. *Acta physiol Scand,* 49 Suppl 169, 1-92.

Åstrand I (1988) Physical demands in worklife. *Scand J Work Environ Health,* 14 suppl 1, 10-13.

Åstrand I, Åstrand P-O, Hallbäck I & Kilbom Å (1973) Reduction in maximal oxygen uptake with age. *J Appl Physiol,* 35(5), 649-654.

Åstrand P & Rodahl K (1986) Body dimensions and muscular exercise. In: Åstrand P & Rodahl K eds. *Textbook of work physiology - Physiological bases of exercise.* Pp 391-411, 3nd ed. ed, New York: McGraw-Hill Book Company.

Åstrand P-O & Ryhming I (1954) A nomogram for calculation of aerobic capacity (physical fitness) from pulse rate during submaximal work. *J Appl Physiol,* 7, 218-221.

Östlin P (1988) Negative health selection into physically light occupations. *J Epidem Comm Health,* 42, 152-156.

Appendix

A. Condensed version of items in papers I, III, IV and V

	Scale:
Work and leisure time:	
• Perceived general exertion	semi-continuous I
• Proportion of the day spent sitting	continuous
• Proportion of the day using VDT	continuous
• Proportion of the day with whole body vibrations	continuous
• Proportion of the day with hand held vibrating tools	continuous
• Precision work exceeding 2 hours per day	ordinal I
• Hands above shoulder level exceeding 30 minutes per day	ordinal I
• Hands below knee level exceeding 30 minutes per day	ordinal I
• Bent or twisted body postures several times per hour	ordinal I
• Repetitive hand or finger movements several times per minute exceeding 2 hours per day	ordinal I
• Occurrence of lifting/carrying loads between 5 and 15 kg	ordinal I
• Occurrence of lifting/carrying loads exceeding 15 kg	ordinal I
Physical training:	
• No. of high-intensity physical training sessions per week	ordinal II
• No. of medium-intensity physical training sessions per week	ordinal II
• No. of low-intensity physical training sessions per week	ordinal II
• No. of body-building sessions per week	ordinal II

B Condensed version of items in paper II

Items used both in 1989 and 1995

• Perceived general exertion	semi-continuous II
• Sitting, kneeling or squatting	ordinal III
• Head bent forward >20 degrees	ordinal III
• Head rotation >45 degrees	ordinal III
• Hands above shoulder level	ordinal III
• Trunk bent forward >60 degrees	ordinal III
• Trunk rotated 45 degrees	ordinal III
• The same hand movements several times per minute	ordinal III
• The same finger movements several times per minute	ordinal III
• Lifting or carrying burdens weighing between 1 and 5 kg	ordinal IV
• Lifting or carrying burdens weighing between 6 and 15 kg	ordinal IV
• Lifting or carrying burdens weighing between 16 and 45 kg	ordinal IV

Items used only in 1995

• Proportion of the day spent sitting	continuous
• Hands below knee level exceeding 30 minutes per day	ordinal I
• Repetitive hand or finger movements several times per minute exceeding 2 hours per day	ordinal I

C. Response scales used for the items in appendixes A and B.

Semi-continuous I			Semi-continuous II		
	6			0	
	7	Very, very light		1	Very, very light
	8			2	
	9	Very light		3	Very light
	10			4	
	11	Fairly light		5	Fairly light
	12			6	
	13	Somewhat hard		7	Somewhat hard
	14			8	
	15	Hard		9	Hard
	16			10	
	17	Very hard		11	Very hard
	18			12	
	19	Very, very hard		13	Very, very hard
	20			14	

Continuous

Not at all ⊢——————————⊣ All the time

Ordinal I

Almost never/ not at all	1-3 days per month	One day per week	2-4 days per week	Every work day [1]
☐ (1)	☐ (2)	☐ (3)	☐ (4)	☐ (5)

Ordinal II

Almost never/ not at all	About once a week	2-3 times a week	> 3 times a week
☐ (1)	☐ (2)	☐ (3)	☐ (4)

Ordinal III

Not at all	A little, approx. 1/10 of the time	Approx. 1/4 of the time	Half of the time	Approx. 3/4 of the time	Almost all the time
☐ (1)	☐ (2)	☐ (3)	☐ (4)	☐ (5)	☐ (6)

Ordinal IV

Not at all	Less than once an hour	1-10 times an hour	11-30 times an hour	More than 30 times an hour
☐ (1)	☐ (2)	☐ (3)	☐ (4)	☐ (5)

[1] For leisure time the wording was "Every day"