

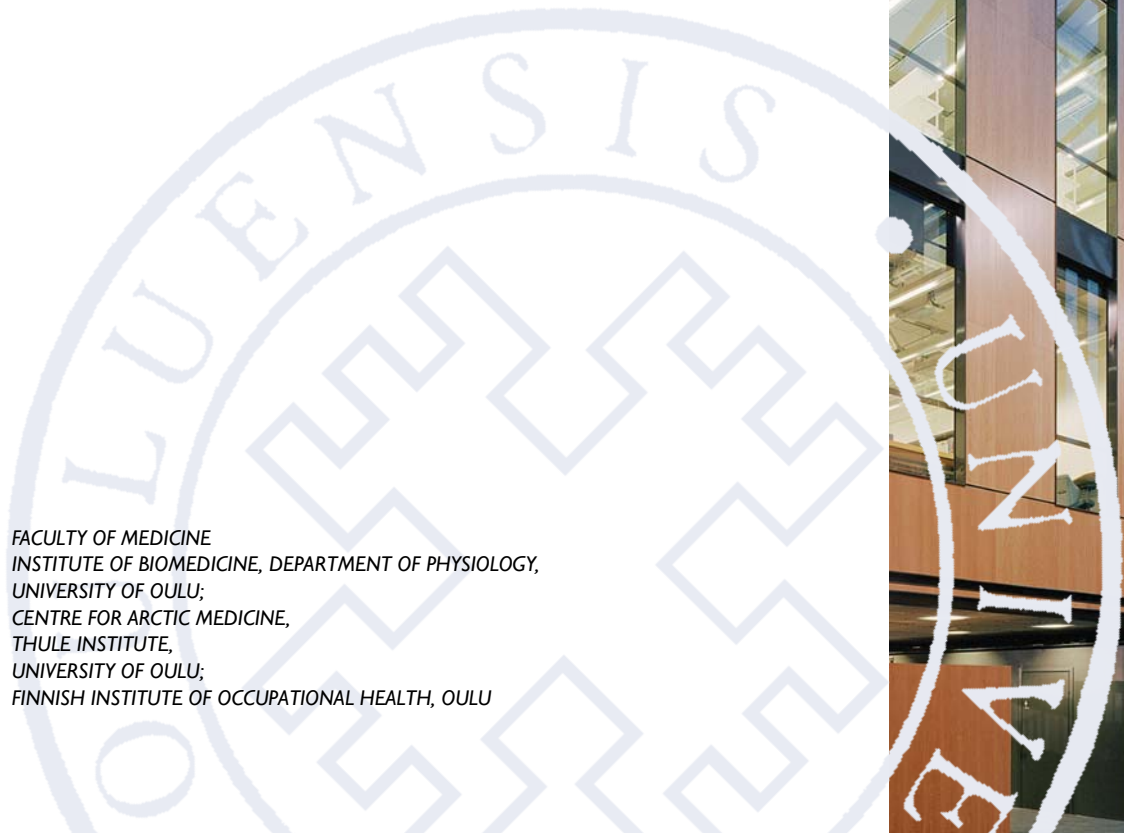
Erja Sormunen

REPETITIVE WORK IN THE COLD

**WORK ABILITY, MUSCULOSKELETAL SYMPTOMS
AND THERMAL AND NEUROMUSCULAR
RESPONSES IN FOOD INDUSTRY WORKERS**

FACULTY OF MEDICINE
INSTITUTE OF BIOMEDICINE, DEPARTMENT OF PHYSIOLOGY,
UNIVERSITY OF OULU;
CENTRE FOR ARCTIC MEDICINE,
THULE INSTITUTE,
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ERJA SORMUNEN

REPETITIVE WORK IN THE COLD

Work ability, musculoskeletal symptoms and thermal
and neuromuscular responses in food industry workers

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the Faculty of Medicine of the University of Oulu for
public defence in the Auditorium of Kastelli Research
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Abstract

The objectives of the study were to evaluate factors associated with work ability and musculoskeletal symptoms among food industry workers, to evaluate thermal and neuromuscular responses during repetitive work in the cold and to find out whether cold-induced deterioration in neuromuscular function can be prevented by using additional torso heating or altering work intensity during repetitive work at 4°C.

A questionnaire study (1,117 respondents) and measurements of physical work strain (18 subjects) were performed among workers in food-processing industry. The impact of changes of ambient temperature (16 subjects) and work intensity (8 subjects) on thermal responses and neuromuscular function was evaluated during repetitive work in laboratory conditions.

The results from the questionnaire study indicated that self-assessed poor work ability and musculoskeletal symptoms were associated with impaired individual health resources and work-related factors, including higher number of years working in the cold, experience of draught and body cooling at work. Measurements during repetitive work in cold food-processing facilities showed that muscular strain was localized in forearm muscles. Laboratory studies showed that compared with 19°C, repetitive work at 4°C increased muscular strain in forearm and upper arm extensors significantly only in men, although the level of muscular strain remained lower and mean skin temperature higher compared with women. Working at 4°C indicated more continuous activation of the working muscles compared with work at 19°C. By intermittently increasing the workload at 4°C the more continuous activation could be counteracted, thus leading to lower strain and fatigue of the working muscles. Additional torso heating did not affect muscular strain of the working muscles at 4°C.

In conclusion, the results indicate a multifactorial feature of work ability and musculoskeletal symptoms among workers in food-processing industry. Gender affects both thermal and neuromuscular responses, which should be considered in the area of work demands and work organization in cold conditions. Altering work intensity could be considered beneficial for reducing muscular strain during repetitive work in cold conditions.

Keywords: cold temperature, electromyography, food-processing industry, gender, musculoskeletal diseases, repetitive work, workload

"Pikku jutut ovat osa kokonaisuutta. Kokonaisuudesta muodostuu täydellisyys. Ja täydellisyys, niin, se ei olekaan pikkujuttu" (Michelangelo 1475–1564)

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This study was carried in co-operation with the Centre for Arctic Medicine at the Thule Institute of the University of Oulu, the Finnish Institute of Occupational Health, Oulu, and the Department of Physiology at the University of Oulu.

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I am privileged to be able to share the important things in my life with my father Raimo and my sister Tytti with her family. I express my gratitude for their love and constant support during my life. The most important and the dearest team of all I have at home with my husband Petri and our daughters Kia, Nea and Pinja. They give me happiness and love in my everyday life. I dedicate this book to our daughters who, like many other little girls, are fond of fairytales about princesses. I hope that with careful reading they will find the Cinderella story in this book, too. The story of Cinderella has truly been a central theme during this research project – as a fairytale with the girls, as findings in muscle physiology, and sometimes as me, working like Cinderella: the first to get up and the last to go to bed.

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Virpiniemi, July 2009

Erja Sormunen

List of abbreviations and definitions

| | |
|--------------------|--|
| aEMG | averaged electromyography |
| AVA | arterio-venous anastomoses |
| B | brachioradialis muscle |
| BB | biceps brachii muscle |
| BMI | body mass index (kg/m^2) |
| $^{\circ}\text{C}$ | Celsius |
| C | cold conditions, the ambient temperature of 4°C |
| C_{work} | continuous workload, at 10% maximal voluntary contraction |
| CI | confidence interval |
| CIVD | cold-induced vasodilatation |
| CLO | thermal insulation of clothing, $0.155 \text{ m}^2 \text{ }^{\circ}\text{C}/\text{W}$ |
| CTS | carpal tunnel syndrome |
| CV | cold conditions with the vest, the ambient temperature of 4°C with the additional torso heating |
| DE | deltoideus muscle |
| ECR | extensor carpi radialis muscle |
| ED | extensor digitorum muscle |
| EMG | electromyography |
| EMG gap | electromyographic gap, physiological gap, spontaneous short periods of muscular activity less than $20 \mu\text{V}$ for at least 0.3 s |
| % MEMG | percentage of the maximal electromyographic activity |
| FAT % | percent of body fat |
| FCR | flexor carpi radialis muscle |
| FDS | flexor digitorum superficialis muscle |
| ISO | International Organization for Standardization |
| I_{work} | intermittently increased workload, at 10 and 30% maximal voluntary contractions |
| M | metabolic rate (W/m^2) |
| MF | median frequency |
| MVC | maximal voluntary contraction |
| OR | odds ratio |
| RPE | rating of perceived exertion, Borg-scale |
| RSI | repetitive strain injury |
| T_{m} | muscle temperature ($^{\circ}\text{C}$) |
| T_{re} | rectal temperature ($^{\circ}\text{C}$) |

| | |
|----------|--|
| T_{sk} | mean skin temperature (°C) |
| TB | triceps brachii muscle |
| TN | thermoneutral conditions, the ambient temperature of 19 °C |
| TRA | trapezius muscle |
| TRP | transient receptor potential |
| WAI | Work Ability Index |
| WHO | World Health Organization |

List of original papers

This thesis is based on the following papers, which are referred to in the text by their Roman numerals:

- I Sormunen E, Remes J, Hassi J, Pienimäki T & Rintamäki H (2009) Factors associated with self-estimated work ability and musculoskeletal symptoms among male and female workers in cooled food-processing facilities. *Industrial Health* 47(3): 271–282.
- II Sormunen E, Oksa J, Pienimäki T, Rissanen S & Rintamäki H (2006) Muscular and cold strain of female workers in meatpacking work. *International Journal of Industrial Ergonomics* 36(8): 713–720.
- III Sormunen E, Rissanen S, Oksa J, Pienimäki T, Remes J & Rintamäki H (2009) Muscular activity and thermal responses in men and women during repetitive work in cold environments. *Ergonomics* 52(8): 964–976.
- IV Oksa J, Sormunen E, Koivukangas U, Rissanen S & Rintamäki H (2006) Changes in neuromuscular function due to intermittently increased workload during repetitive work in cold conditions. *Scandinavian Journal of Work, Environment & Health* 32(4): 300–309.

In addition, some unpublished data are presented in the thesis.

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1 Introduction

Disability in daily activities due to musculoskeletal disorders is a major factor of human suffering, healthcare use, absence from work and early retirement. In the Finnish population over 30 years of age, almost every fifth working subject and more than every third non-working subject had some musculoskeletal disorder (Taimela *et al.* 2007). Based on the statistics of the Social Insurance Institution of Finland (2008), over 30% of all sickness benefit periods in Finland were due to musculoskeletal disorders, indicating that over 272 million euros (€) were paid in compensation for sick leave days due to musculoskeletal disorders. More specifically, repetitive strain injuries of the upper extremities constitute 32%, i.e. over €70 million of all compensated sick leave days due to musculoskeletal disorders. The incurred costs of rehabilitation of these injuries amount to over €6 million yearly (Kelasto 2009). Despite rehabilitation, employees are not always able to return to work. Based on the Statistical yearbook of pensioners in Finland (2008), in 2007, 24% of all disability pensions were granted due to musculoskeletal disorders. The corresponding monetary compensation is over €702 million yearly (Pensioners and insured in Finland 2007 2008). The indirect costs, e.g. loss of productivity, are more difficult to estimate, but they often play an important role when the prevalence of musculoskeletal disorders concerns working-age people (Martimo *et al.* 2009).

In terms of public health, the major risk factors for musculoskeletal disorders are harmful physical workload, traumatic injuries, overweight, low level of physical activity during leisure time and smoking (Heliövaara *et al.* 2007). Work-related musculoskeletal disorders in the upper extremities are common among workers performing repetitive and forceful manual work, with awkward or extreme wrist positions (Yassi 1997, Shiri *et al.* 2009). Repetitive work in combination with local cold exposure of the hands has been found to be a contributing factor for upper extremity disorders (Chiang *et al.* 1990) and impairment in neuromuscular function (Oksa *et al.* 2002). Exposure to above-mentioned physical work features, high repetitiveness and cold ambient temperature, is typical e.g. in the cold stores in shops and in the fish- and meat-processing industry where large parts of production facilities are cooled because of hygienic reasons.

Occupational exposure to cold may have adverse effects on human performance and health. Body cooling causes thermal discomfort, decreased performance and may increase the risk for cold-related diseases and injuries

(Hassi *et al.* 2005). Working in cold environment has also been found to be associated with an increased risk of occupational accidents (Chau *et al.* 2008). Several cross-sectional studies (Piedrahita *et al.* 2004, Bang *et al.* 2005, Aasmoe *et al.* 2008) and reviews (Campbell 1999, Hildebrandt *et al.* 2002, Tappin *et al.* 2006) have shown cold work as a major risk factor for musculoskeletal symptoms and general health problems in the food-processing industry.

According to the Finnish Register of Occupational Diseases, maintained by the Finnish Institute of Occupational Health, the highest risk for the incidence of repetitive strain injuries is in food-processing industry. The incidence of repetitive strain injuries has been reported to be 74 cases per 10,000 employed workers, being 14-fold higher compared to the average of all professions (Karjalainen *et al.* 2008). Due to the adverse impact of both cold and repetitive work on human health and performance, work productivity, quality and safety, national regulations (Decree of the Council of State 2001) and international standards (EN 1005-5 2007, ISO 15743 2008) give instructions for appropriate assessment and management practices in repetitive work in cold conditions.

The purpose of the study was to evaluate factors associated with work ability and musculoskeletal symptoms, to evaluate thermal and neuromuscular responses during repetitive work in food-processing industry and to find out whether cold-induced deterioration in neuromuscular function can be prevented by using additional torso heating or altering work intensity during repetitive work at 4 °C.

2 Review of the literature

2.1 Working in food-processing industry

2.1.1 Cold conditions indoors

The food-processing industry, employing ca 35,000 workers, comprises the fourth largest field of industry in Finland. The main branches in the food-processing industry are meat-processing, dairy, bakery, brewing and soft drinks facilities (Statistics Finland 2009). A significant part of the production and dispatching facilities in the meat-processing industry are cooled due to hygienic reasons. Requirements concerning working conditions and the processing of food products are stated in the Finnish legislation, e.g. Food Act 23/2006 and Decree of the Ministry of Agriculture and Forestry 37/EEO/2006. Regulation (EC) No 853/2004 of the European Parliament and of the Council lays down specific hygiene rules for sorting out and packing, and for stockholding meat products; the indoor temperatures in meat-processing facilities should be between 2 and 7 °C.

From a physiological viewpoint, cold environment can be defined as an environmental condition that activates the thermoregulatory system to diminish heat loss from the body to the environment or that causes uncomfortable sensations of cold (Rintamäki *et al.* 2005). According to the international standard of Ergonomics of the thermal environment (BS 7915 1998), air temperature of 12 °C or less is considered cold indoor environment. In addition to cold ambient temperature, workers in meat-processing industry face other environmental factors, such as humidity, air movements, draught and noise, cold working surfaces and handling cold products (Griefahn *et al.* 1997, Campbell 1999). According to ISO 15743 (2008), air velocity in the meat-processing industry is less than 0.2 m/s, humidity about 80%, and temperatures of the products and working surfaces are 3 to 4 °C, or even -2 °C, when handling iced meat.

In 2002, the regulation about physical examinations concerning work with specific risk of illness (Decree of the Council of State 2001) came into effect in Finland. The employer has the responsibility to organize, at the beginning of the career and regularly at 1- to 3-year intervals, physical examinations for the workers who are exposed to detrimental physical factors, such as abnormal ambient temperatures, i.e. cold or hot environment. The International Organization for Standardization (ISO) has prepared standards and documents

concerning the ergonomics of the thermal environment. A newly prepared standard, ISO 15743 (2008), describes the practical methods for health and workplace risk assessment and management in cold environment. The strategy for assessments follows a three-stage screening procedure (Figure 1). In the first stage, cold-related hazards at work and workers' responses are identified by observations and health checks conducted by, for example, foremen, work safety delegates or workers, and occupational health professionals, respectively. In the second stage, it is recommended that quantification of the observed cold-related problems be carried out by occupational health professionals using specific measurements, including calculation of the clothing insulation required (IREQ, ISO 11079 2007), estimation of the thermal properties of clothing (clo, ISO 9920 2007), wind/air movement, temperature measurements, and interviews of individual cold-related health problems. During the evaluation phase, guidance and information for planning and managing work is provided. If unsolved problems still remain, special solutions for health and workplace promotion are provided by experts in the third stage. According to ISO 15743 (2008) the purpose of a risk assessment and management plan would be to systematically take into consideration different aspects related to cold, and to guarantee the implementation of different management activities. The objective is to integrate the model into the occupational health and safety management system and practices of the company.

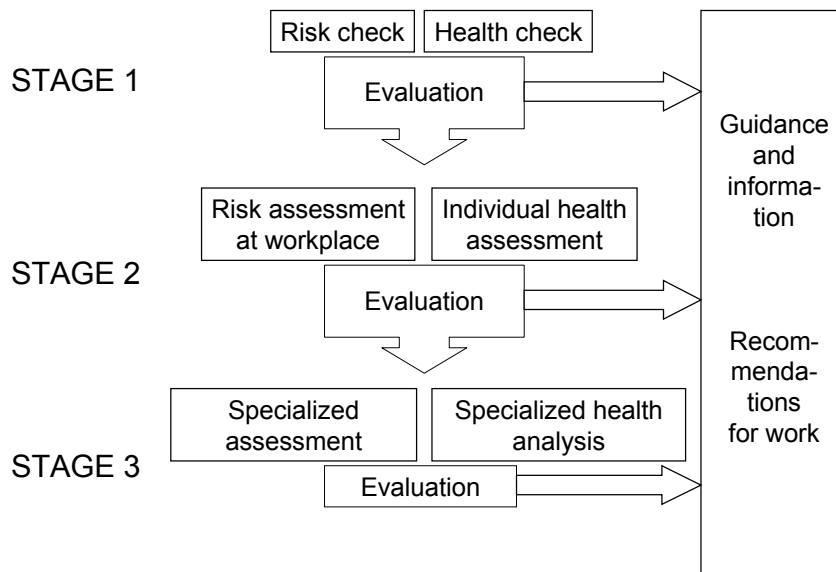


Fig. 1. The model for the assessment of workplace risks and individual health (ISO 15743 2008).

2.1.2 Repetitive work

Work tasks in the food-processing industry are usually repetitive and monotonous, and workers are expected to perform their tasks at a high rate of speed while the ergonomics factors are not always the most favourable (Campbell 1999). Exposure to both unpleasant work environment and high repetitiveness is assumed to increase the risk for health problems (Chiang *et al.* 1990, Griefahn *et al.* 1997, Oksa *et al.* 2002).

Repetitive work can be defined as work where short and similar work cycles, with closely resembling force exertion patterns and trajectories, are repeated at high frequency. In the review of Kilbom (1994b) different definitions for repetitiveness are given, mainly according to the length of single work cycles. For a definition of high repetitiveness the following has been widely used in literature:

single cycle time of less than 30 seconds, or more than 50% of the cycle time involves performing the same type of motion; this can be used as criterion for high repetitive jobs (Silverstein *et al.* 1986, Keyserling *et al.* 1993, Ketola *et al.* 2001, EN 1005-5 2007). However, there is no consensus concerning minimum duration of repetitive work. It is assumed that repetitive work performed continuously for a minimum of 60 minutes is considered to be repetitive (Kilbom 1994a, Colombini 1998). Rather than cycle times, Kilbom (1994a) has emphasized movement frequencies when defining guidelines for risk assessment in repetitive work. As an example, in the wrist and elbow regions more than 10 movements per minute are regarded as high frequency of movements in repetitive work.

In Finland, Occupational Safety and Health Act No 738/2002 provides regulations about work and working conditions. The concept of repetitive strain is addressed in Section 24, where provisions on ergonomics of the workstation, work postures and work motions are discussed. According to this “it shall be ensured that the hazard caused by repetitive strain to the employee is being avoided, or if this is not possible, it is minimized”. The employer is under obligation to analyse the workload factors and to avoid or reduce the risk from the observed hazard (Occupational Safety and Health Act No 738 / 2002).

Various machine-related actions may require repetitive handling at high frequency. The European Standard, EN 1000-5 (2007), presents a model for assessing and controlling health and safety risks due to machine-related repetitiveness. The purpose of the standard is to reduce health risks including musculoskeletal strain and disorders. The first stage is to identify hazards that may expose to risks during machine-related actions. If possible hazards are observed, estimation and a simple evaluation of the risk factors, including repetitiveness, force exertion, working postures and movements, duration of work periods and recovery times, is presented. If the possible risk factors are defined, a more detailed analysis of the impact of each risk factor should be evaluated with reference to the OCRA method (Occupational Repetitive Action). When the OCRA index shows an unacceptable risk level, it should be reduced by optimising the following factors: e.g. the number of technical actions needed in a work cycle, cycle time, awkward postures, level of force, recovery periods and job rotation.

2.2 Human thermoregulation in the cold

Thermoregulation is a physiological system involving both autonomic and behavioural means to maintain body temperatures within a restricted range under conditions involving variable internal and external heat loads (IUPS Thermal Commission 2001). Air temperature, radiant temperature, humidity and air movement are the essential environmental parameters which affect human responses to thermal environment. Human responses, instead, are dependent on changes in cutaneous circulation and metabolic heat generated by muscle activity and the clothing worn by the person. These basic factors define human thermal environments with which humans are in a constant, dynamic interaction.

2.2.1 Human thermal balance

Body temperature reflects the relationship between internal heat production and heat transfers between the body and ambient temperature. This relationship is described as:

$$M - W = K \pm C \pm R \pm E \pm S \text{ [W/m}^2\text{]},$$

where metabolic rate of the body (M) provides energy to enable the body to do mechanical work (W). At least 75% of chemical energy is transformed into heat. Heat transfer from the body occurs by conduction (K), convection (C), radiation (R) and evaporation (E). The sum of these processes is heat storage (S), which represents heat gain by the body if it is positive, or heat loss from the body if it is negative. When the body is in heat balance, the rate of heat storage is zero (S = 0) (Parsons 2003.)

“The range of environmental temperatures at which temperature regulation is achieved only by control of sensible heat loss, i.e. without regulatory changes in metabolic heat production or evaporative heat loss” is known as thermoneutral zone (IUPS Thermal Commission 2001). For a naked individual at rest, the ambient temperature for thermoneutrality varies between 25 and 27 °C in air temperature (Erikson *et al.* 1956). As humans are homeotherms, internal body temperature is maintained at ca. 37 °C with a circadian fluctuation of 0.5 to 0.7 °C. In contrast to the more precisely regulated core temperature, temperature of the outer part of the body, “shell”, can vary within external environmental conditions.

2.2.2 Neuronal control of temperature regulation

Temperature sensitive receptors, either warm- or cold-responding, are located in surface and core body parts including the brain, spinal cord and abdomen. Reduced tissue temperature activates the cold receptors in free nerve endings which are four to ten times as many as warm receptors. The mechanism of cutaneous thermoreception has been identified, and it is stated that changes in temperature are mediated by special temperature-sensitive ion channels. These ion channels belong to the transient receptor potential (TRP) family of non-selective cation channels (Nomoto *et al.* 2004, Morrison *et al.* 2008).

Thermal information from cutaneous thermoreceptors is transmitted via the spinothalamic pathway to the thalamus where the signals are projected to the somatosensory cortex, leading to perception and discrimination of cutaneous temperature. The anterior part of hypothalamus, the preoptic region, controls heat loss and the posterior part of hypothalamus regulates heat-generating mechanisms. The efferent signals for cutaneous vasoconstriction and heat production are mediated via the autonomic nervous system (Nomoto *et al.* 2004, Morrison *et al.* 2008).

Thermal sensation is interrelated to how a person “feels”; it is a sensory experience and a psychological phenomenon (ISO 10551 1995). Thermal sensations can be expressed as a function of absolute temperature of the skin, rate of change of skin temperature and the size of the stimulus area. However, thermal sensitivity differs in various regions of the body due to the number of receptors in a specific region (Hensel 1981).

2.2.3 Adjustment of heat loss

The initial consequence of cold exposure is a cutaneous vasoconstriction leading to reduction in skin temperatures. Increased tone in cutaneous veins reduces blood flow in the skin and the periphery, directing blood into deeper veins and to the core. This cold-induced vasoconstriction reduces heat loss from the skin to the environment by increasing tissue insulation, reducing conductive heat transfer and minimizing exposure of warm blood to the cold environment (Ducharme & Tikuisis 1991, Stocks *et al.* 2004). In addition to cutaneous vasoconstriction in the extremities, counter-current exchange of heat reduces the temperature difference between artery and vein, and minimizes heat loss through the skin because heat is recycled instead of being dissipated. Due to vasoconstriction, venous blood from

the skin is cold, and conversely, arterial blood returning from the body core is warm. As blood flows from the core, it enters arteries in the extremities that lie next to veins carrying blood returning from the skin. The warm arterial blood transfers heat to the returning venous blood and becomes cooler as it enters the skin, hence reducing heat loss (Jiji *et al.* 1984, Song *et al.* 1987).

After severe cooling for 5 to 10 min, and at finger skin temperatures below 12 °C, an anomalous reaction, cold-induced vasodilatation (CIVD), occurs: blood vessels in the fingers vasodilate, which increases blood flow and temperature of the fingertips. After this CIVD, the blood vessels start to contract again, leading to falls in skin temperature (Daanen 2003). This cyclic change in skin temperatures, repetition of the periods with vasodilatation and vasoconstriction, has also been called “hunting response” (Lewis 1930). Normally, connections between the arterial and venous circulation take place via capillaries. However, direct connections, arterio-venous anastomoses (AVA), between the arterial and venous network are found in the fingers, elbows, lips, cheeks, and nose. AVAs are thought to be involved in CIVD, because of the finding that CIVD occurs only at the AVA locations (Daanen 2003.) Many individual factors, e.g. age, gender, physical and mental health status, adaptation and acclimatization to cold, affect the occurrence of CIVD (Daanen 2003).

2.2.4 Adjustment in heat production

In a cold environment, the major sources of heat production in healthy adults occur through basic metabolic processes and muscular activity. Most energy, converted in the chemical process by oxidation of organic compounds (fat, carbohydrates and proteins), is released as heat, while the energy for external work varies from 0 to 25% of total metabolic rate, indicating relatively low mechanical efficiency of the working muscles (Parsons 2003). The average resting metabolic rate in healthy adults produces approximately 65 W/m² or about 115 W heat. During intense physical activity the metabolic rate may be increased almost 5 times compared to the resting level (ISO 8996 2004). Aerobic physical exercises have been used as a method for increasing circulation and tissue temperatures (Rintamäki *et al.* 1992, Oksa *et al.* 1996). The most obvious rewarming effect of exercise in cold conditions has been detected above the working muscles (Rintamäki *et al.* 1992).

Metabolic heat production is increased by shivering (Haman 2006). Shivering is regarded as “an increase in the rate of heat production during cold exposure due

to increased contractile activity of skeletal muscles not involving voluntary movements and external work” (IUPS Thermal Commissions 2001). Shivering thermogenesis begins from the increased thermoregulatory muscle tone. During shivering, when the muscles themselves perform no external work, virtually all the energy of contraction is converted into heat. The effect of shivering on heat production can be 5-fold above the resting levels of metabolic rate (Eyolfson *et al.* 2001). The intensity of cold shivering is higher in the central and proximal muscles, ranging from 5 to 16% of maximal voluntary contraction (MVC), compared to 1 to 4% of MVC in the distal muscles (Bell *et al.* 1992, Meigal *et al.* 1998).

Chemical heat production includes the actions of calorogenic hormones and the stimulation of brown fat metabolism. During prolonged intense cold exposure, the excretion of thyroid hormones is increased, leading to increased cellular metabolism and heat production (Leppäluoto *et al.* 2005). Activation of the sympathetic nerve system in response to cold increases the excretion of noradrenaline to circulation and to the brown fat cells. Noradrenaline activates e.g. lipolysis and the generation of free fatty acids (FFA). Free fatty acids open the mitochondrial channel protein, uncoupling protein 1 (UCP-1), causing an influx of protons into mitochondria and production of heat instead of adenosine triphosphate (ATP). Other calorogenic hormones, e.g. glucocorticoids, insulin and glucagon, have a minor effect in the thermogenetic processes (Leppäluoto *et al.* 2005).

2.2.5 Individual factors affecting human thermoregulation in the cold

Anthropometry influences human thermal responses in cold. Tissue thermal insulation is formed by the combined thickness of skin, adipose tissue and skeletal muscle. Subcutaneous fat, which is poorly perfused and contains less water compared with skeletal muscle, forms a layer of thermal insulation. Individuals who have a high percent of body fat (fat %) maintain their core temperature better (Keatinge 1960, Degnbol & Quaade 1964), but have lower skin temperatures compared with leaner subjects (LeBlanc 1954, Baker & Daniels 1956, Degnbol & Quaade 1964).

Individuals with a bigger body size have a favourable surface area-to-mass ratio, indicating increased insulation of mass and metabolic heat production compared with smaller individuals (Anderson 1999, Stocks *et al.* 2004). Gender-related differences in thermoregulation have also been associated with differences

in anthropometry, with a larger body surface area-to-mass ratio in women compared to men. This was confirmed by Tikuisis *et al.* (2000), who found that after normalizing the thermoregulatory responses against body mass or surface area no significant gender differences were found in body cooling or metabolic heat production between men and women immersed in water at 18 °C. However, in women, the internal body temperature fluctuates by about 0.5 °C according to the menstrual cycle phase as well (Kaciuba-Uscilko & Grucza 2001). In addition, it has been documented that greater cutaneous vascular response to local cooling in women may explain lower skin temperatures in cold exposure compared with men (Cankar & Finderle 2003). Furthermore, women have been found to be more sensitive to draught and have more often cool and uncomfortable sensations compared with men (Griefahn & Küнемund 2001).

Ageing is associated with reduced peripheral vasoconstriction and decreased metabolic heat production, leading to enhanced heat loss in body temperature in cold environment and impaired defence mechanisms to maintain core temperature in the cold (Kenney & Munce 2003, DeGroot & Kenney 2007). However, it has been found that age-related decline in resting metabolic rate is mainly related to a decrease in physical activity rather than changes in body composition (Krems *et al.* 2005, Lührmann *et al.* 2009).

Habits of daily life have been related to the basal metabolism rate. Individuals with higher basal metabolism and better physical fitness have been found to have better cold tolerance compared with individuals with lower basal metabolism and physical fitness (Maeda *et al.* 2005). Acute prior physical exercise has been found to predispose to greater heat loss from the body in response to exposure to cold conditions (Castellani *et al.* 1999).

Cold adaptation affects human physiological responses, providing benefits to humans working in cold environments (Bittel 1987, Leppäluoto *et al.* 2001). The first sign of cold adaptation is habituation, due to which physiological responses and discomfort to cold become less pronounced (LeBlanc 1992, Leppäluoto *et al.* 2001). There are four types of cold adaptation: 1) insulative adaptation characterized by enhanced heat conservation mechanism, 2) metabolic adaptation characterized by increased heat production mechanisms, 3) hypothermic adaptation characterized by greater cooling, thus reducing heat loss, and 4) insulative-hypothermic adaptation, which is intermediate between insulative and hypothermic adaptation (Hammel 1963).

Certain personality traits have been found to be related to thermal responses in the cold. Higher levels of extraversion traits strengthen the autonomic

thermoregulatory responses and feeling of cold discomfort, whereas an increased level of neuroticism has an opposite effect (LeBlanc *et al.* 2003, LeBlanc *et al.* 2004, LeBlanc & Ducharme 2005).

2.3 Physical performance in the cold

The neuromuscular system, like nearly all biological structures, is remarkably temperature sensitive. Variations in tissue temperature result in changes in muscle function and electromyographic (EMG) activity of the muscle (Rutkove 2001).

2.3.1 Effect of cooling on muscular performance

Studies concerning the change in human muscular performance due to cooling have been carried out both during lower extremity exercises (Winkel & Jørgensen 1991, Bell 1993, Oksa 1998) and during upper extremity or hand exercises (Hammaskjöld *et al.* 1992, Cornwall 1994, Oksa *et al.* 2002). Although the exposures used to cause cooling vary in terms of length (from minutes to hours), substance used (water or air) and region of exposure (local or whole body), the common objective of the studies is to cause tissue cooling.

It has been shown that the effect of temperature on muscular performance is mostly determined by muscle temperatures (Bergh & Ekblom 1979). Generally, the decrease in dynamic muscular performance after cooling varies between 3 to 6% \cdot $^{\circ}\text{C}^{-1}$ decrease in muscle temperature (T_m) (Bergh & Ekblom 1979, Sargeant 1987, Ferretti *et al.* 1992), while the decrease in isometric muscular performance has been found to be minor, 2% \cdot $^{\circ}\text{C}^{-1}$ decrease in T_m (Bergh & Ekblom 1979). While the above-mentioned studies were performed after cold water immersion, Oksa *et al.* (1997) reported that relatively low level of muscle cooling at the ambient temperature of 20 $^{\circ}\text{C}$, decreased muscular performance by 17% \cdot $^{\circ}\text{C}^{-1}$ in T_m in dynamic exercises. Isometric endurance time of the muscular work, instead, has been found to be improved (Petrofsky & Lind 1980, Thornley *et al.* 2003) or to remain unaffected (Holewijn & Heus 1992) after cooling.

In cooled muscles, the contractile and force generating factors have been shown to be impaired (Davies & Young 1983, Faulkner *et al.* 1990, Hopf & Maurer 1990, Bigland-Ritchie *et al.* 1992): the velocity of muscle contraction, shortening and lengthening is decreased (Faulkner *et al.* 1990, Hopf & Maurer 1990), and time for tension development and relaxation is increased with decreasing muscle temperatures (Davies & Young 1983, Hopf & Maurer 1990,

Bigland-Ritchie *et al.* 1992). Muscle contraction velocity may be related to the degree of diminution in muscular performance in cooled muscles, indicating that the fast-twitch fibres are more susceptible to cooling than slow-twitch fibres (Oksa *et al.* 1995). Sargeant (1987) demonstrated a velocity-dependent effect on temperature-related power output changes, and showed that the maximum peak force was inversely related to the pedalling rate in cooled muscles.

Decrease in local skin temperatures, without changes in deep core temperature, has also been found to produce significant impairment in force production during maximal isokinetic contractions (Cheung & Sleivert 2004, Comeau *et al.* 2003). This may explain why individuals suddenly exposed to cold environments have difficulties in performing work tasks or muscular exercises even before core cooling (Cheung & Sleivert 2004).

2.3.2 Effect of cooling on electromyographic activity

Changes in the temperatures of the muscle (Madigan & Pidcoe 2002, Petrofsky & Laymon 2005) and skin (Oksa *et al.* 2002, Piedrahita *et al.* 2008) have been found to result in changes in the electromyographic (EMG) activity of the muscle.

As skin temperature decreases the amplitude component of EMG increases during dynamic (Winkel & Jørgensen 1991, Hammaskjöld *et al.* 1992, Oksa *et al.* 2002, Piedrahita *et al.* 2008) and isometric exercises (Bell 1993, Meigal *et al.* 1998, Sovelius *et al.* 2007). However, others have reported decreased EMG amplitude during brief isometric contractions (Petrofsky & Lind 1980, Mucke & Heuer 1989). On the contrary, Holewijn & Heus (1992) showed that skin cooling did not influence EMG amplitude during isometric contraction. More detailed analysis of the EMG activity of the agonist-antagonist muscle pair has revealed contradictory changes in the EMG after cooling. During concentric muscle contraction, when the muscle is assumed to contract most effectively, EMG amplitude in the agonist muscle decreases, whereas the activity of the antagonist muscle increases (Oksa *et al.* 1997).

Changes in the frequency parameters of EMG have been reported to be more uniformly affected by cooling: decreasing both during dynamic (Petrofsky & Lind 1980, Winkel & Jørgensen 1991, Holewijn & Heus 1992, Rissanen *et al.* 1996, Coulange *et al.* 2006) and isometric muscle contractions (Madigan & Pidcoe 2002, Stewart *et al.* 2003). However, Meigal *et al.* (1998) showed that EMG frequency was not significantly affected after a 6 °C decrease in T_{sk} at ambient temperature

of 10 °C, whereas during visible shivering, a 6.5 °C decrease in T_{sk} decreased the frequency component of the EMG during isometric upper extremity exercises.

Piedrahita *et al.* (2008) found that T_{sk} cooling by 4.6 °C reduced the number and duration of electromyographic gaps (EMG gaps) in working muscles during repetitive work in cold conditions at the ambient temperature of 10 °C compared with similar work in thermoneutral conditions at 25 °C. The reduction of EMG gaps may refer to a more continuous activation of the working muscle fibres underneath the measuring electrodes. The occurrence of EMG gaps can be considered to indicate that normal variation in fibre recruitment takes place in working muscles (Westgaard & De Luca 1999). The reduction of EMG gaps has been found to be related to a more frequent prevalence of musculoskeletal problems (Veiersted *et al.* 1993). The effect of cooling on the occurrence of EMG gaps has not been commonly studied.

2.3.3 Explanations for the cooling-induced changes in electromyographic activity

There could be several explanations for the changes in EMG activity including an increment in the recruitment of motor units because of alteration in the recruitment thresholds (Yona 1997), alteration in the order of motor unit recruitment (Faulkner *et al.* 1990) and alteration in the excitability of the motoneuron pool and muscle spindle activity (Oksa *et al.* 2002). In addition, diminution of muscle fibre conduction velocity has been found during muscle cooling (Mucke & Heuer 1989, Petrofsky & Laymon 2005), and it is stated that a slower conduction velocity may result in an increased temporal summation, causing enhanced EMG amplitude of the muscle contraction (Winkel & Jørgensen 1991, Oksa *et al.* 2002). Furthermore, decrease in conduction velocity has been found to be directly related to the decrease in EMG frequency during cooling of the muscle (Mucke & Heuer 1989).

Cooling modifies the duration, amplitude and shape of motor unit action potentials (Buchthal *et al.* 1954, Rutkove 2001), which may affect the interpretation of the EMG activity of the muscle. With decreasing muscle temperature, the motor unit action potential duration has been shown to increase (Buchthal *et al.* 1954, Bigland-Ritchie *et al.* 1992, Bertram *et al.* 1995, Coulange *et al.* 2006). Buchthal *et al.* (1954) and Bigland-Ritchie *et al.* (1992) found a decrease in the amplitude of action potential, while Ricker *et al.* (1977) and Hopf & Maurer (1990) showed an increased response to cooling. Increased frequency

of motor unit action potentials has been found after focal nerve cooling (Bertram *et al.* 1995).

2.4 Work ability and hazards related to work in the cold

According to Ilmarinen & Tuomi (2004), work ability can be described as the balance model, where individual resources correspond to the work demands in a healthy and safe way. Dimensions of work ability can be related to the interactions between individual resources, including the worker’s health and functional capacity, the worker’s professional competence, and worker’s attitudes and motivation, and the work itself, including e.g. work demands and environment, work organization and the work community. In addition, social relationships outside work and societal factors form an important frame and background for the human work ability (Ilmarinen & Tuomi 2004).

Exposure to cold ambient temperatures may be a risk for health and cause cold-related health and performance degradations, illness and cold-induced injuries (Mercer 2003, Hassi *et al.* 2005). The risk of occupational accidents may also be increased due to cold working conditions (Chau *et al.* 2008). The main features associated with occupational cold comprise four stages: 1) thermal discomfort and pain sensation due to excessive heat loss from the body, 2) decrement in manual performance due to cooling, 3) the risk for cold injuries, initiation and aggravation of health symptoms or accidents, and 4) protection against cooling calls for special ergonomic requirements (Holmér 1994).

Table 1 presents approximate thermal strain criteria for the physiological parameters (Lotens 1993).

Table 1. Approximate thermal strain criteria for physiological parameters (Modified from Lotens 1993).

| Variable | Comfort | Discomfort | Performance degradation | Tolerance | Damage |
|-----------------------------|---------|------------|-------------------------|-----------|----------------------|
| Mean skin temperature (°C) | 33 | < 31 | < 30 | < 25 | < 15 (time dep.) |
| Finger temperature (°C) | 27–34 | < 20 | < 15 | < 5 | -2 << 15 (time dep.) |
| Rectal temperature (°C) | 37 | – | < 37 | < 35 | < 28 (time dep.) |

Complaints of unpleasant working environment, cold-induced discomfort and feeling of fatigue and pain at work have been found to be common among workers at low ambient temperature in the meat-processing industry (Krapac *et al.*

1997, Campbell 1999). Moreover, studies have shown that workers in the meat-processing industry, at low ambient working temperatures, have an increased risk for musculoskeletal and skin disorders as well as infectious and respiratory diseases (Campbell 1999). Health problems, e.g. abdominal and intestinal problems, headache and chronic cough, were also more common among cold store workers at temperatures of -5 to $+5$ °C compared to their controls at normal environmental temperatures (Chen *et al.* 1991). In addition, muscle, airway and skin symptoms were more frequently reported among workers who often felt cold at work compared to workers who never felt cold at work in seafood industry at an ambient temperature of 2 to 18 °C (Bang *et al.* 2005).

Inaba *et al.* (2005) found that regardless of the higher prevalence of cold-related complaints of feeling fatigue and health problems, e.g. in stomach, intestines and menstrual cycle, among workers in colder working temperatures compared to workers in warmer conditions, no significant differences in work difficulty due to cold were found between groups working under different environmental temperatures. In each work environment, the ambient temperatures during the workday ranged between 5 and 10 °C, 12 and 17 °C and 11 and 21 °C. On the contrary, Tuomi *et al.* (2001) reported that poor physical climate of the work environment, either heat, cold or changing temperature, was significantly associated with poor work ability among ageing workers aged 55–62 years. The ambient temperatures were not specified.

Low job control, i.e. workers' chance to influence their duties and strategies of working, has been found to be an important factor contributing to sickness absences among food-processing workers (Arola *et al.* 2003). In an 11-year follow-up study among food industry workers, Salonen *et al.* (2003) found that poor work ability was significantly associated with early exit from work. However, it has been shown that perceived work ability among workers in food factory can be maintained or promoted by workplace health promotion intervention programmes, including general health promotion, advised physical training, or work organizational changes, including training for changes in working culture and methods and participatory planning of workplace health promotion (Nygård & Arola 2004).

Anttonen & Virokannas (1994) assessed cold stress in outdoor occupations using body cooling in relation to the recommended temperature limits for degradation of performance by Lotens (1993). They examined body cooling as changes in mean skin temperature (T_{sk}) and concluded that work ability may be reduced, at least temporarily, because of lowered T_{sk} during the workday.

2.5 Musculoskeletal disorders in the cold

Today, the work requirements in many occupations have changed, and not much in the way of muscle power is required during work tasks. The work is characterized by repetitive, low-force muscular work done by small muscles mainly in the upper extremities. Such forces must be maintained for prolonged periods, which may expose to muscle fatigue and therefore increase the likelihood of work-related musculoskeletal disorders (Sjøgaard & Søgaard 1998.)

Musculoskeletal disorders cover a wide range of inflammatory and degenerative diseases and disorders which result in pain and functional impairment (Buckle & Devereux 2002). The pathogenesis of muscles, tendons, ligaments, joints, peripheral nerves and supporting blood vessels is included in the entity of musculoskeletal disorders (Buckle & Devereux 2002, Punnett & Gold 2003). Repetitive strain injury (RSI) is a general term for disorders that develop as a consequence of physical work stressors including repetitive and forceful motions, static muscle load and mechanical stress, vibration and extreme temperatures, and awkward postures (Yassi 1997). Common disorders that arise as RSIs are carpal tunnel syndrome, epicondylitis, and tendinitis of the wrist or hand (van Tulder *et al.* 2007).

Several prospective epidemiological studies (Macfarlane *et al.* 2000, Andersen *et al.* 2003, Nahit *et al.* 2003, Andersen *et al.* 2007) and reviews (Viikari-Juntura & Silverstein 1999, Barr *et al.* 2004, Palmer & Smedley 2007) have quantified the association between highly repetitive work and the increased risk for the onset of neck-shoulder and upper extremity disorders. The association between exposure to cold conditions and the increased risk for musculoskeletal disorders has been discussed in the reviews by Jin *et al.* (2000) and Pienimäki (2002).

Local cold exposure of hands in combination with high repetition of hand movements has been found to increase the risk for carpal tunnel syndrome (CTS) 9.4-fold after adjustments for gender, age and the length of employment. The respective value for the occurrence of CTS was 2.2-fold in repetitive work alone in thermoneutral working conditions (Chiang *et al.* 1990). Furthermore, a significant temperature-induced effect on the incidence of wrist disorders has been found among female sausage packers compared with female sausage makers during a 31-month follow-up study in a Finnish meat-processing factory. Female sausage packers working at the ambient temperature of 8 to 10 °C have a 1.5 times higher risk of tenosynovitis or peritendinitis compared to female sausage

makers working at the ambient working temperature of 20 °C (Kurppa *et al.* 1991).

In addition, several cross-sectional studies have indicated that a low ambient temperature or damp working climate indoors may increase the risk of pain in the lower back (Chen *et al.* 1991, Piedrahita *et al.* 2004, Dovrat & Katz-Leurer 2007, Aasmoe *et al.* 2008), neck/shoulder (Griefahn *et al.* 1997, Bang *et al.* 2005, Aasmoe *et al.* 2008), shoulder (Pope *et al.* 1997, Niedhammer *et al.* 1998, Piedrahita *et al.* 2004), upper extremity (Viikari-Juntura *et al.* 1991, Kim *et al.* 2004, Piedrahita *et al.* 2004, Aasmoe *et al.* 2008) and knee (Chen *et al.* 1991) (Table 4).

In the review of Hildebrandt *et al.* (2002), the epidemiological evidence about the relationship between climatic factors and musculoskeletal symptoms was assessed as weak; regardless of that, researchers, patients and workers in unsatisfactory working conditions consider the relationship plausible. However, in their own (Hildebrandt *et al.* 2002) empirical study, poor climatic factors, cold, draught, dampness and changes of temperature, were found to be associated, as a causal or aggravating factor, with the incidence of low back and neck-shoulder symptoms.

Table 4 in Appendix presents 22 articles about the association between cold working condition indoors and the occurrence of musculoskeletal symptoms and disorders.

2.5.1 Explanations for the cold-related musculoskeletal disorders

The multifactorial origin of musculoskeletal symptoms is generally accepted and although the cold exposure, as stated above, can be regarded as a contributing factor for the symptoms and disorders, the underlying pathophysiological mechanisms for these problems is not evident (Malchaire *et al.* 2001).

A cooling-induced decrease in muscular performance and co-ordination, and an increase in muscular strain and fatigue (Oksa 2002) may associate with the higher occurrence of musculoskeletal symptoms and disorders in cold conditions. In addition, increased stiffness of joints and reduction in speed of movements resulting from the increased viscosity of the synovial fluid due to cold may act as a possible mechanism for the symptoms, because muscles have to exert greater force for normal work movements in low ambient temperatures compared with work at higher temperatures (Hunter *et al.* 1952). A comparable mechanism for the factor triggering musculoskeletal symptoms in upper extremities may be the

cooling-related decrease in tactile sensitivity and manual dexterity associated with greater finger grip forces (Cheung *et al.* 2008).

The Cinderella hypothesis presented by Hägg (1991) suggests that myalgic pain originates from damaged low-threshold muscle fibres as a result of prolonged activation and too short recovery time. These fibres belong to low-threshold motor units which are recruited at the onset of muscle activation and are continuously firing until the muscle is completely relaxed (Hägg 1991, Sjøgaard & Søgaard 1998). The Cinderella hypothesis has been supported by findings that a low rate of EMG gaps, i.e. short silent periods or resting periods of muscle, has been found to be associated with higher prevalence of musculoskeletal symptoms in the shoulder region (Veiersted *et al.* 1990, Veiersted *et al.* 1993, Hägg & Åström 1997, Sandsjö *et al.* 2000). A smaller number of physiological gaps has also been found during low-level upper extremity repetitive work in cold conditions (Piedrahita *et al.* 2008), which may partly explain the association between more frequent occurrence of musculoskeletal problems and cold conditions.

Inter-individual differences in the sensitivity to changes in weather conditions, such as cold weather or dampness, has been found to be associated with painful joints, muscles or arthritis (Jamison *et al.* 1995, Strusberg *et al.* 2002, von Mackensen *et al.* 2005). Psychosocial work stressors, including psychological workload, inadequate working conditions and monotonous work, have also been related to the increased risk of musculoskeletal disorders (Walker-Bone & Cooper 2005, Elfering *et al.* 2008). Elfering *et al.* (2008) found that workers with high levels of work stressors have elevated excretion rates of norepinephrine during work, and also higher levels of musculoskeletal pain (Elfering *et al.* 2008). The relationship between the increased level of norepinephrine and musculoskeletal problems cannot be confirmed by cross-sectional study, and demonstrating the causal relationship between these factors is problematic. However, this would be an interesting viewpoint between the prevalence of musculoskeletal problems and exposure to cold working conditions, because the concentration of norepinephrine is known to be increased as a normal hormonal response to cold exposure (Leppäluoto *et al.* 2005).

3 Aims of the study

The purpose of the study was to evaluate self-assessed work ability and disadvantage in daily activities due to musculoskeletal symptoms among food industry workers, and to evaluate thermal and neuromuscular responses during repetitive work in cold conditions.

The detailed aims of the study were as follows:

1. To describe the factors associated with poor work ability and disadvantage in daily activities due to musculoskeletal symptoms among workers in cold conditions in the food-processing industry.
2. To find out thermal responses and muscular strain among female workers during meat-packing work in cold conditions.
3. To find out the effects of cold ambient temperature and additional heating on the torso on thermal responses and neuromuscular function in men and women during repetitive work at 4 °C.
4. To find out the effect of intermittently increasing workload of low-intensity repetitive work on neuromuscular function in cold conditions at 4 °C.

4 Material and methods

4.1 Subjects

The study sites and the physical characteristics of the subjects in studies I, II, III, IV are presented in Table 2.

All the experiments were on a voluntary basis and the personal data of the respondents were not disclosed. All the subjects were instructed about the purpose of the studies. In studies II, III and IV, the subjects were informed of the details of the experimental procedures, the associated risks and possible discomfort. Before the measurements each subject was examined by a physician to assure that they did not have any upper extremity disorder. Contraindications for participating in the study were for example rheumatoid arthritis, diabetes, Raynaud's phenomenon and any other disorder or trauma in the upper extremities. A written informed consent was obtained from each subject. The experimental protocol was approved by the Ethics Committee of the Hospital district of Helsinki and Uusimaa.

Study I was carried out as a questionnaire study in seven Finnish food-processing factories (5 meat-processing factory and 2 dairies) in the year 1997. A total of 1,117 workers (response rate 85%) responded in the study. The study population consisted of workers in various work tasks: meat packers, carvers and forklift drivers, arrangers in stores and dispatching departments. The respondents were divided into two different age groups: younger employees aged 18 to 39 years (68.5%) and older employees aged 40 to 64 years (31.5%). The physical characteristics of the subjects who responded to the study are presented in Table 2.

Study II was carried out in one large meat-processing factory where 18 female meat-packing workers volunteered as test subjects (Figure 2). They were right-handed and non-smokers. All the subjects had worked for at least 6 months on the same tasks and were experienced meat-packing workers (Table 2).



Fig. 2. Test subject during sausage packing in a food-processing factory (Study II).

Studies III and IV were carried out in laboratory conditions and a total of 24 college or university students (13 males and 11 females) participated. In Study III, sixteen non-smokers and healthy 20- to 30-year-old students volunteered as test subjects for the experiments. There were eight women and eight men, all of them right-handed.

Study IV consisted of two different measurements: IV A and IV B. Test subjects in study IV A were the same as in study III. In Study IV B, eight (five men and three women) non-smoking, healthy persons volunteered for the experiments.

Table 2. Study sites and physical characteristics of the subjects. The values are means \pm SD.

| Study | Study site | Gender | n | Age | Weight | Height | BMI | Fat % |
|------------|---------------------------|--------|------|-------------|-------------|-------------|------------|----------------|
| Study I | Food-processing factories | men | 603 | 33 \pm 10 | 81 \pm 13 | 178 \pm 7 | 24 \pm 4 | – |
| | | women | 514 | 35 \pm 11 | 64 \pm 10 | 164 \pm 6 | 26 \pm 4 | – |
| | | total | 1117 | 34 \pm 11 | 74 \pm 14 | 172 \pm 9 | 25 \pm 4 | – |
| Study II | Meat-processing factory | women | 18 | 29 \pm 8 | 165 \pm 1 | 66 \pm 13 | 24 \pm 5 | 25.7 \pm 3.7 |
| Study III | Climate chamber | men | 8 | 25 \pm 4 | 179 \pm 4 | 75 \pm 12 | 23 \pm 3 | 14.2 \pm 5 |
| | | women | 8 | 23 \pm 3 | 163 \pm 5 | 57 \pm 4 | 21 \pm 2 | 24.3 \pm 3.3 |
| | | total | 16 | 24 \pm 3 | 171 \pm 9 | 66 \pm 13 | 22 \pm 3 | 19.3 \pm 6.6 |
| Study IV A | Climate chamber | total | 16 | 24 \pm 3 | 171 \pm 9 | 66 \pm 13 | 22 \pm 3 | 19.3 \pm 6.6 |
| Study IV B | Climate chamber | total | 8 | 23 \pm 2 | 175 \pm 7 | 68 \pm 10 | 23 \pm 3 | 16.5 \pm 5.4 |

4.2 Study designs

4.2.1 Questionnaire study (I)

Study I was carried out as a descriptive study with a cross-sectional design. The questionnaire was directed to the workers in the production facilities. For 85% of the respondents, the environmental temperature ranged from 0 to 10 °C. Of the respondents, 11% were exposed to ambient temperatures from 11 to 15 °C. Only 4% of the respondents announced their working temperature as being below 0 °C. The questionnaire included questions on personal data, lifestyle, length of employment, characteristics of working in cold environment (ambient temperature, exposure time and thermal sensations), clothing and cold protection, work ability, general health status and complaints in the musculoskeletal system. A detailed description of the explanatory variables associated with dependent variables, poor work ability and disadvantage in daily activities due to musculoskeletal symptoms, is given in Paper I as appendices.

The questionnaires were delivered by occupational safety personnel in each factory and dairy, and the questions were answered by choosing the appropriate alternative. Some questions included the option of open-ended responses. The questionnaires were completed during working hours and then sent in reply-paid envelopes to the researcher. The study was performed in co-operation with the Finnish Institute of Occupational Health, Oulu, and the Centre for Occupational Safety.

4.2.2 Work place measurements (II)

Study II was carried out as a descriptive study with a cross-sectional design. Measurements took place in five meat-packing departments (sausage, poultry, minced meat, meat product and pancake) at a large food-processing factory in Finland. The term meat-packing is used although one of the departments studied was pancake-packing department. The departments for the study were chosen because of highly manual repetitiveness and the ambient temperature ranging between 4 and 10 °C. In general, air velocity was less than 0.2 m/s and humidity was about 80%. Temperatures of the products handled were usually 3 to 4 °C; occasionally they were even iced, -2 °C. The subjects wore their normal work clothing, including long-sleeved undershirt and long-legged underpants, thermal underwear and special hygienic outerwear developed for meat-packing. Thermal insulation of the clothing used was estimated to be 1.6 clo (0.25 m² °C/W) (ISO 9920 2007). Moreover, cotton gloves covered by thin plastic gloves were used for hygienic reasons. The clo is the empiric unit (1 clo = 0.155 m² °C/W) for thermal insulation, describing the capacity of the clothing to prevent heat loss from the skin to the environment (ISO 9920 2007).

The work in Study II was mainly performed in a standing position on an assembly line. The working surfaces were not adjustable, but if necessary the platforms below the workers' feet were used for adjusting the working surfaces to elbow level. The main task in each department was to sort out and pack the products (sausages, pancakes, drumsticks, fillet of meat, marinated steak and beef burgers), which weighed 125–550 g, on the assembly line. The handled products were usually cool, moist and on some occasions icy. Observations made during the measurements by the author (Sormunen E) revealed that work movements included bilateral extension, flexion and deviation of the wrists, and pronation and supination of the forearms. Muscular work was more dynamic for the upper extremities compared with the shoulder region, where the muscular work was more static. The single work phase was repeated on average every 2–6 seconds, depending on the department or the handled product. On average, one work period lasted 30–90 minutes in different departments. Between each work period there was a break (about 8 minutes every hour and a 35-minute lunch break) in warm conditions at about 20 °C. Average measuring time was 3.5 hours, consisting of three to four work periods depending on the departments. The subjects performed their normal tasks during the measurements.

4.2.3 Laboratory studies (III, IV)

Studies III and IV were experimental studies with comparative cross-sectional designs. Both were carried out in a climatic chamber with controllable air temperature and air humidity.

In study III, the work simulation study, two different environmental conditions were used to compare the effect of cold ambient temperature on thermal responses and muscular activity during a 2-hour work simulation. Thermal exposures were once at 19 °C (range 18.7 to 19.3 °C, thermoneutral, TN) and twice at 4 °C (range 3.7 to 4.3 °C), without (cold, C) and with additional thermal protection on torso, the heating vest (cold with the vest, CV). The subjects wore the same clothing as in Study II with the addition of the electric heating vest, which was worn between thermal underwear and outerwear at the second exposure at 4 °C. Gloves were not worn. The vest consisted of three panels (30 ° 47 cm), one in front of the body and two panels on the back, with 50 W power output by each panel. The power supply was controlled by regular evaluation of thermal sensations and ensuring that the skin temperature in the upper torso did not exceed 38 °C. One or more panels were turned off if necessary.

The simulation model was chosen to suit the work in the sausage-packing department in a food-processing factory. The products handled were artificial sausages which corresponded to real products in the sausage-packing department. They were about 12 cm long, 3.5 cm in diameter and 125 g in weight. The artificial sausages were in packed groups of four, with the sausages bound together with string at one end. During the simulation, test subjects picked up the four-packed product (500 g) from the right side of the body using the right hand. Then the product group was divided between both hands (two sausages in both hands), while the string kept the products together. The string between the sausages was touched against a blade, thus simulating the cutting phase in the factory. After the cutting phase, the four-pack product group was moved back to the right hand and placed into a box located in front of the body (Figure 3A). This single work phase lasted three to four seconds and was repeated ten times. After this, the test subject moved the box (5.5 kg) filled with artificial sausages, from the front of the body to the right side of the body and took the empty box from their right side and placed it on the table in front of them. This work simulation was continuous, lasted for 30 minutes and was repeated four times (altogether 120-minute exposure). Between each 30-minute period, there was a five-minute rest at the same ambient temperature. The simulated cutting phase was

standardized by changing the height of the blade so that during the cutting phase (wrist flexion and extension) elbow joints were at 100–110°. The work rate was paced by a metronome to 15 work phases per minute. In order to minimize the interference of a possible learning effect, the subjects practised the work simulation on a separate visit before the first experiment.

Study IV consisted of two different sub studies: work simulation (A) and intermittent work (B) study. The work simulation study was performed to evaluate whether the neuromuscular function is impaired during sausage packing simulation in a cold environment. The simulation model was the same as in Study III. Measurements were carried out at the ambient temperatures of 19 °C and 4 °C. The subjects wore the same clothing as in Study II without the heating vest. Intermittent work study was performed to evaluate whether cold-induced deterioration in neuromuscular function can be restored by intermittently increasing the workload of low-intensity repetitive work. The measurements were performed twice at 4 °C. Relative humidity was 30% (range 25 to 35%) and air velocity less than 0.5 m/s. The intervening time between the exposures was at least 2 days. The subjects wore a T-shirt, shorts, tracksuit and jogging shoes. The estimated thermal insulation of the clothing was 0.9 clo. During the exposures the subjects performed six 20-minute work bouts (total duration 120 minutes). Each participant was seated with the hip and elbow angle adjusted at 90 degrees. The participant held a handle in his or her hand, the handle and the palm of the hand in a vertical position, and a metal wire running through a pulley system was attached to the handle. A load, corresponding to either 10% MVC (maximal voluntary contraction force of the wrist flexors) or 30% MVC, was fixed to the other end of the wire. Starting with their wrist fully extended, each participant flexed the wrist every third second to the full free range of joint motion and returned the hand back to the starting position (Figure 3B). These dynamic concentric-eccentric contractions were paced with a metronome so that there were 20 contractions per minute. The participants performed flexion-extension repetitive work in a sitting position, first in a continuous 10% MVC wrist flexion-extension model (C_{work}) and then the same work with the exception that every fourth minute the workload was intermittently (I_{work}) increased. During I_{work} every fourth minute the subjects performed two consecutive wrist contractions in one second with the 30% MVC load. The 10% MVC workload was chosen because it is recommended that during dynamic work lasting 1 hour or more, the load corresponding to 10% MVC should not be exceeded (Jonsson 1982).

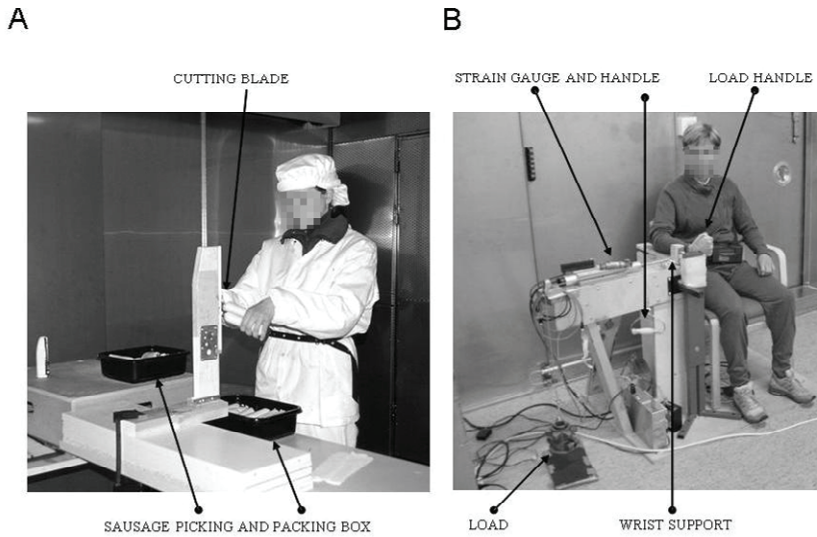


Fig. 3. Experimental setup in the work simulation study (A) and the intermittent work study (B).

4.3 Measurements and calculations

4.3.1 Anthropometry

Body mass index (BMI) is based on the calculation of a person's weight in kilograms divided by height in metres squared (kg/m^2 , WHO 2000).

Percent of body fat (fat %) was assessed from the calculated sum of skinfold thickness of biceps brachii muscle, triceps brachii muscle, subcapularis and crista iliaca, and the estimated fat % was based on the equations presented by Durnin & Rahaman (1967) and Durnin & Womersley (1974). The instrument used was the Harpenden skinfold caliper (John Bull, British Indicators ltd., St. Albans, Hertz, UK).

The validity and reliability of the methods for assessment of human body composition have been discussed in the reviews by Lukaski (1987) and Willett (1998).

4.3.2 Temperatures

The core temperature (T_{re}) was measured by a rectal probe inserted to 10 cm beyond the anal sphincter. Local skin temperatures were measured at 10 to 15 sites using thermistor probes, either YSI (YSI 400 Series, Yellow Springs Instruments, CO., Inc., Yellow Springs, USA, in studies II, III, IV A) or NTC thermistors (Digi-Key, River Falls, MI, USA, in study IV B) at one-minute intervals. Measurement accuracy for the rectal and skin temperature probes was ± 0.1 °C. Two types of loggers were used: Squirrel 1200, Grant UK in studies II, III and IV A, and Hewlett Packard HP 3497, Palo Alto, CA, USA in study IV B.

The mean skin temperature (T_{sk}) was (II–IV) calculated by weighing the local skin temperatures by representative areas according to Hardy and Dubois. T_{sk} was calculated as follows:

$$\text{In study II: } T_{sk} = (0.07 \cdot T_{\text{cheek}}) + (0.05 \cdot T_{\text{palm}}) + (0.14 \cdot T_{\text{extensor side of the forearm}} + T_{\text{flexor side of the forearm}} + T_{\text{shoulder}})/3) + (0.35 \cdot (T_{\text{chest}} + T_{\text{lower back}})/2) + (0.19 \cdot T_{\text{thigh}}) + (0.20 \cdot T_{\text{calf}})$$

$$\text{In studies III and IV: } T_{sk} = (0.07 \cdot T_{\text{cheek}}) + (0.05 \cdot T_{\text{palm}}) + (0.14 \cdot (T_{\text{shoulder}} + T_{\text{flexor side of the upper arm}} + T_{\text{extensor side of the upper arm}} + T_{\text{extensor side of the forearm}})/4) + (0.35 \cdot (T_{\text{chest}} + T_{\text{lower back}})/2) + (0.19 \cdot T_{\text{thigh}}) + (0.13 \cdot T_{\text{calf}}) + (0.07 \cdot T_{\text{foot}}).$$

4.3.3 Muscular activity

To evaluate the level of muscular activity in the studies II-IV, surface electromyographic activity (EMG, ME3000P8, Mega Electronics, Kuopio, Finland) was measured. Pre-gelled bipolar surface electrodes (Medicotest, M-OO-S, Denmark) were placed over the belly of the muscle and the distance between recording contacts was 2 cm. Ground electrodes were attached above inactive tissue. Observations made by the researchers in the meat-processing factory revealed highly dynamic muscular work for upper extremities (Study II); the locations for EMG electrodes were thus decided to be the following (Figure 4): the wrist flexors (flexor carpi radialis, FCR and flexor digitorum superficialis FDS muscles) and wrist extensors (extensor digitorum, ED, brachioradialis, B and extensor carpi radialis, ECR muscles), upper arm extensors (triceps brachii muscle, TB) and upper arm flexors (biceps brachii muscle, BB), and muscles in the shoulder region (anterior and medial parts of deltoideus, DE and trapezius,

TRA muscles). The detailed placements of the EMG electrodes are presented in the original papers II, III and IV.

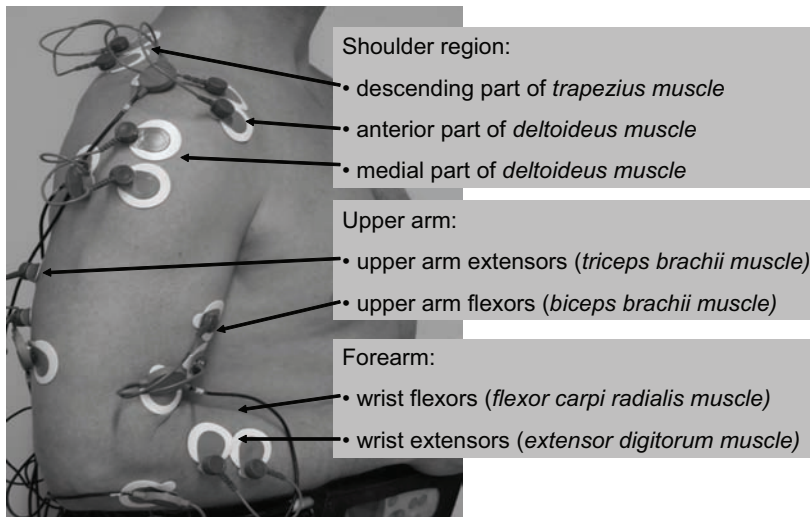


Fig. 4. Placements of the electromyography (EMG) electrodes in the shoulder region, forearm and upper arm in the Study III.

The EMG signals from the skin above the working muscles were acquired with a sample rate of 1000 Hz. The measured signal was amplified 2000 times (preamplifier situated 10 cm apart from the measuring electrodes) and the signal band between 20 and 500 Hz was full-wave rectified and averaged (aEMG) with a 0.1-second time constant. Relative muscular strain was defined as the percentage of the maximal EMG activity (% MEMG), by calculating the aEMG during work in relation to that measured during maximal voluntary contraction (MVC). To assess the frequency component of the EMG (median frequency, MF), the power spectrum was estimated by moving fast Fourier transform (FFT window, 512 points). The frequency of EMG gaps was analysed according to the following criteria: EMG activity less than 20 μV at least for 0.3 seconds per 1 minute (Figure 5).

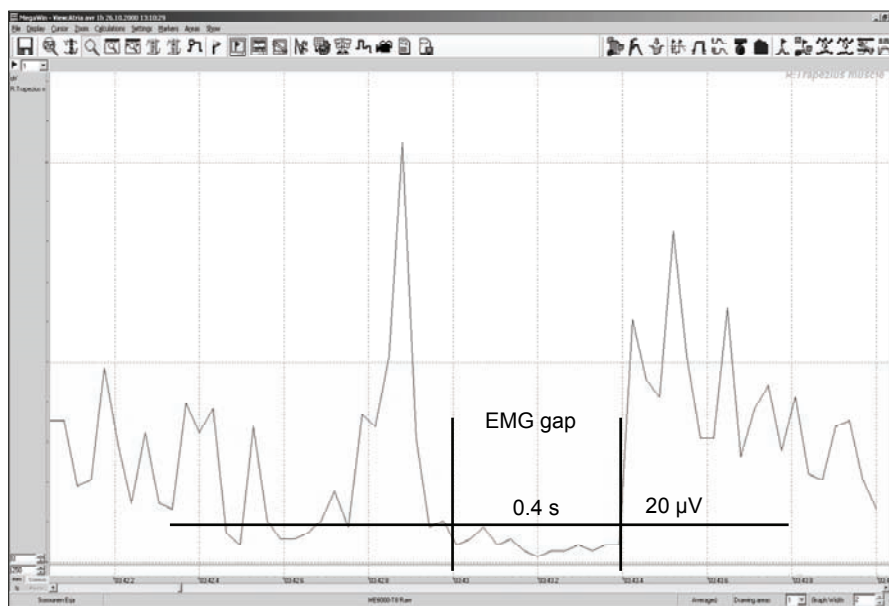


Fig. 5. An example of the existence of EMG gap in trapezius muscle during sausage packing simulation when the following criteria were fulfilled: EMG activity less than 20 μV at least 0.3 seconds (Study III).

The test-retest reproducibility of the EMG measurements with the surface electrodes, retesting after 2 hours, has been reported to be high: intra-class correlation coefficient values ranging from 90% to 99%, depending on the muscles measured during the repetitive lifting task (Ebenbichler *et al.* 2002). In cold conditions at 10 °C, the reproducibility of EMG measurements, expressed as coefficient of variation (SD divided by mean), has been reported to be less than 7% (Oksa 1998).

4.3.4 Force measurement

Maximal voluntary contraction (MVC) tests were performed isometrically at thermoneutral conditions at 19 °C. For the EMG normalization procedure, detailed descriptions for the MVCs are presented in Papers II, III and IV as appendices.

In studies III and IV, the force produced by the maximal flexion of the wrist was measured as the test subject was seated with the hip and elbow angle adjusted at 90 ° (as in Figure 2B). The subject held a handle in his or her hand, with the handle and the palm of the hand in a vertical position, attached to the strain gauge (Newtest Inc, Oulu, Finland). The strain gauge was fixed to a level place at a right angle to the armrest and connected to a computer for further analysis. The forearm was fixed to the armrest of the chair so that only motion of the wrist joint was allowed. MVC of wrist extension was measured while the subject was standing, with forearm on the table and the wrist joint at the edge of the table. The forearm and hand were in pronation, and the subject held a handle in his or her hand, pulling it maximally upwards in the direction of the extension.

The maximal force level was analysed from the MVC data, and a decrease in the MVC value was considered a sign of muscle fatigue. The measuring frequency of the strain gauge was 200 Hz. In this study (Study III), the reproducibility of the wrist flexion and extension force measurement (16 subjects, 3 consecutive performances), expressed as coefficient of variation (standard deviation / mean · 100), was 4% and 8% for extension and flexion, respectively.

4.3.5 Perceived exertion and thermal sensations

Perceived exertion (RPE, Borg 1998) during meat-packing (Study II) and work simulation study (Study III) was assessed using the 15-grade scale from no exertion at all (6) to maximal exertion (20). In healthy adults, the validity between this Borg's RPE scale and heart rate has been found to be moderate, the correlation coefficient ranging from 0.58 to 0.62 (Chen *et al.* 2002, Karavatas & Tavakol 2005).

Thermal sensations (ISO 10551 1995) were estimated using a 9-grade scale from extremely hot (4) to extremely cold (-4), neutral level (0) presenting neither cold nor warm sensations. Perceived exertion and thermal sensations were recorded at 15- to 20-minute intervals (Studies II–IV). Validity and reproducibility of using this scale has been discussed in ISO 10551 (1995).

4.3.6 Work ability and disadvantage in daily activities due to musculoskeletal symptoms

The concept of work ability has been operationalized by subjective estimation of the current work ability compared with the lifetime best, being one of the seven

items in the Work Ability Index (WAI, Tuomi *et al.* 1997a). Estimation of current work ability was compared with the lifetime best using a scale ranging from 0 to 10 points, indicating classification from unable to work to lifetime best work ability.

In this thesis, the variable was then categorized into two classes. Points 1 to 6 represented the lowest 11% of the respondents and were categorized as poor work ability (Kujala *et al.* 2005). Points 7 to 10 represented 89% of the respondents and were categorized as good work ability. Both WAI (Kujala *et al.* 2006) and the item-oriented assessment of self-assessed current work ability (Alavinia *et al.* 2009) have shown significant predictive value for sickness absence and receiving disability pension. In the review of Ilmarinen & Tuomi (2004), the item of current work ability compared with lifetime best was shown to have the strongest effect for assessing the reliability of WAI. According to de Zwart *et al.* (2002), the test-retest reliability of WAI has been described as acceptable at both individual and group level.

The prevalence of musculoskeletal symptoms causing disadvantage in daily activities was coded into a two-class model: “disadvantage due to symptoms” or “no disadvantage due to symptoms”. In the original questionnaire the classification of disadvantage due to musculoskeletal symptoms entailed four classes. The same query was used in the study by Koskinen *et al.* (1997) evaluating work ability among workers in bakeries in the food-processing industry.

4.4 Statistical analysis

The data were presented as mean values with standard error, and as mean values with standard deviations. The analyses were performed using SPSS software for Windows (version 15.0, SPSS Inc., Chicago, IL, USA). Statistical significances were accepted at $p < 0.05$.

In study I, descriptive statistics was used to evaluate the background information of the data. Cross-tabulation with Pearson Chi-Square and binary logistic regression analyses were used to evaluate the associations between the explanatory variables and dependent variables. Odds ratios (OR) and their 95% confidence intervals (95% CI) were calculated for the explanatory variables.

In study II, repeated measures ANOVA, followed by Scheffe’s post hoc test was used to compare mean values of muscular activity and skin and rectal temperatures between the work periods. Skin cooling during single work periods

was tested by paired samples t-tests and the difference in T_{sk} at the beginning and at the end of the last work period compared with the respective values during the first work period was tested by one-sample t-tests. Bivariate correlation with Pearson's correlation coefficients was used to measure the strength of correlation between muscular strain and skin temperatures.

In study III, repeated measures ANOVA was used to test the equality of mean values in muscular activity, muscular strength and thermal responses (skin and rectal temperatures and thermal sensations) between the work periods and between thermal exposures. For multiple comparisons, the observed p-values were adjusted using the Bonferroni method. Independent samples t-test was used to compare gender differences. Bivariate correlation with Pearson's correlation coefficient was used to measure the strength of correlation between muscular activity and skin temperatures, and between maximal isometric strength and muscular activity.

In study IV, mean values of muscular activity, muscular function and skin and rectal temperatures were compared by paired samples t-test within one exposure and between exposures.

Further analyses in the number of electromyographic gaps were performed by paired samples t-test and by independent samples t-test.

5 Results

5.1 Factors associated with poor work ability among food industry workers (I)

Men and women assessed their work ability similarly, and no gender difference was observed. The risk for poor work ability had a significant association with the length of employment, being more than two-fold higher after 15 years of working in cold conditions (Odds ratio, OR 2.24, 95% confidence interval, CI 1.03 to 4.86). In an unadjusted analysis, poor work ability was already significantly associated with the length of employment after 4 years of working in cold conditions.

Of the work environmental factors, only the experience of draught (OR 1.55, CI 1.00 to 2.40) was significantly associated with poor work ability after adjustment for other risk factors. A cold work environment was initially associated with poor work ability (OR 1.46, CI 0.98 to 2.17), but the association became weaker after adjustment for other explanatory variables.

The risk of poor work ability was more than six times higher (OR 6.37, CI 3.24 to 12.53) among workers who had 25 to 60 sick leave days per year compared to workers who had no absences. Meanwhile, the risk was lower (OR 3.77, CI 1.35 to 10.54) among those who had more than 60 sick leave days compared to those with 25 to 60 days of absence. Moreover, a physically inactive lifestyle was associated with poor work ability, and the risk was almost twice as high (OR 1.84, CI 1.02 to 3.32) for those who did not engage in physical activity during leisure time compared to those who exercised at least twice a week. The original tables for the logistic regression analysis of poor work ability are presented as appendices to Paper I.

5.2 Factors associated with disadvantage in daily activities due to musculoskeletal symptoms among food industry workers (I)

In the last 12 months, disadvantage in daily activities due to musculoskeletal symptoms was most common in the neck and shoulder region and in the shoulders, wrists and lower back. More than half of the respondents (52%) reported pain in the neck-shoulder region to cause disadvantage in daily activities, pain intensity ranging from “some” to “much”. The proportion of respondents

reporting respective pain in both wrists and shoulders was 36%, and the corresponding figure for lower back pain was 41%. The original tables for the logistic regression analysis of musculoskeletal symptoms are presented in the appendices to Paper I.

Symptoms in the neck-shoulder region. The prevalence of neck-shoulder region pain causing disadvantage in daily activities was the highest among those who experienced “extensive neck-shoulder cooling”, the odd ratios being 5.88 (CI 2.20 to 15.72) among younger employees aged 18 to 39 years, and 8.37 (CI 1.25 to 55.95) among older employees aged 40 to 64 years. Young female workers reported pain in the neck-shoulder region over twice as often compared with young men (OR 2.55, CI 1.58 to 4.11), whereas disadvantage in daily activities due to neck-shoulder region pain was more common among older workers with poor self-assessed work ability compared to those with good work ability. The proportion of disadvantage in daily activities due to neck-shoulder region pain was higher among older employees (86%) compared to younger employees (81%, $p < 0.05$).

Furthermore, in the unadjusted analysis, those who exercised 1 to 2 times a week in their leisure time were 1.6 times more likely to report pain in the neck-shoulder region compared to inactive persons. However, the significance disappeared when the frequency of physical exercises exceeded 2 times per week. Similarly, in the unadjusted analysis the association between neck-shoulder pain and the length of employment became significant after four years on the job (OR 1.77, CI 1.08 to 2.88), but the statistical significance disappeared after adjustment for the other risk factors.

Symptoms in the shoulder region. Local shoulder cooling was associated with disadvantage in daily activities due to shoulder pain. The proportion of workers with this pain was the highest among those who reported extensive cooling (OR 6.32, CI 2.54 to 15.74). Exposure to the same work for more than four years (OR 1.60, CI 1.00 to 2.56) and self-assessed poor work ability (OR 1.77, CI 1.00 to 3.13) were associated with increased prevalence of shoulder pain.

In contrast to the results for neck-shoulder pain, gender was not significantly associated with the experience of shoulder pain. Among the older employees, after adjustment for the risk factors, leisure-time physical activity 1 to 2 times a week was associated with increased prevalence (OR 3.03, CI 1.13 to 8.16) of shoulder pain; however, the significance was not present when the frequency of physical exercises increased to over 2 times per week. The prevalence of shoulder

pain was more common among older employees (78%) compared to younger employees (54%, $p < 0.001$).

Symptoms in the wrist. The experience of wrist cooling was associated with disadvantage in daily activities due to wrist pain, being the highest for those younger (OR 25.82, CI 11.94 to 55.85) and older (OR 17.96, CI 5.18 to 62.31) employees who reported “extensive cooling”. The occurrence of wrist pain was higher for female workers (OR 1.72, CI 1.18 to 2.52), compared with male workers only in the younger age group. In the unadjusted analysis, both history of more than 15 years of cold work (OR 1.88, CI 1.10 to 3.22) and poor self-assessed work ability (OR 2.08, CI 1.30 to 3.31) were associated with the increased prevalence of wrist pain, but these associations did not remain significant after adjustment for other factors.

There were no statistically significant differences in the prevalence of wrist pain between the younger and older employees. Further analyses revealed a significant association between low body mass index (BMI) and disadvantage in daily activities due to wrist pain. The prevalence of pain was higher among those with a BMI under 20 kg/m² compared to those with a BMI of 20 to 25 kg/m² (all employees: OR 2.10, CI 1.06 to 4.12 and among younger employees: OR 2.21, CI 1.08 to 4.49).

Symptoms in the low back region. The occurrence of low back pain was the highest among those who experienced “extensive low back cooling”, being significant both among younger (OR 3.88, CI 1.82 to 8.25) and older (OR 38.09, CI 6.99 to 207.64) employees. Self-assessed poor work ability was significantly associated with an increased occurrence of low back pain among younger employees (OR 2.86, CI 1.28 to 6.43). Similarly to shoulder region pain, among the older employees and after adjustment made for the explanatory variables, physical activity 1 to 2 times a week during leisure time was associated with increased prevalence of low back pain (OR 4.25, CI 1.57 to 11.54) compared to having no leisure time physical activity. The significance disappeared when the frequency of physical exercise increased to more than 2 times per week. The prevalence of low back pain was significantly higher among older employees (73%) compared to their younger counterparts (62%, $p < 0.05$).

Obesity (OR 1.73, CI 1.02 to 2.96) and having worked in the same job for four years (OR 2.20, CI 1.45 to 3.33) were initially associated with the increased prevalence of disadvantage in daily activities due to low back pain, but after adjustment for other risk factors the association with the prevalence of low back

pain remained significant only for employees who had worked in the same job for 8 to 15 years (OR 2.00, CI 1.17 to 3.40).

Association between work ability and musculoskeletal symptoms. Those workers who rated their work ability as poor reported significantly more often disadvantage in daily routines due to neck-shoulder ($p < 0.001$), shoulder ($p < 0.001$), wrist ($p < 0.01$) and low back pain ($p < 0.001$) compared with those with good work ability. See Figure 2 in Paper I, as appendix.

5.3 Thermal responses during repetitive work in the cold

5.3.1 Thermal responses among female workers in cold meat-packing facilities (II)

While working in the production departments at ambient temperatures of 4 to 10 °C for 3.5 hours, the mean skin temperature (T_{sk}) decreased from the mean value of 30.7 ± 0.3 °C in the first work period to the mean value of 30.0 ± 0.2 °C in the fourth work period. During each work period, T_{sk} showed a decreasing trend ($p < 0.01$). A similar trend was observed during the whole exposure time: compared with the first work period, T_{sk} was 0.9 °C ($p < 0.001$) and 0.8 °C ($p < 0.001$) lower at the beginning and at the end of the last period, respectively (Figure 6A). The rectal temperature (T_{re}) remained stable during consecutive work periods.

Skin temperatures of different body regions in the upper extremities and the shoulder remained generally stable, without significant differences between the work periods. However, strong fluctuation in skin temperatures was observed according to ambient temperatures, being lower in cold production facilities and higher during pauses in warm conditions. Figure 6B shows that particularly strong fluctuation was found in finger skin temperatures. The mean values of finger skin temperatures during the work periods remained between 19.5 ± 1.7 °C and 20.7 ± 1.2 °C, while the lowest values in finger skin temperatures, e.g. in the third work period, varied from 13 °C to 23 °C.

Forearm skin temperatures above wrist extensors, both in the right and left forearm, and wrist flexors of the right forearm tended to decrease during the first 5 to 10 minutes of each work period. After that, skin temperatures tended to increase towards the end of work periods without, however, significant variations during the work periods (Figure 6C). Instead, skin temperatures above wrist

flexors of the left forearm and shoulder region decreased during each work period by 0.3 to 0.8 °C ($p < 0.05$). The original tables for skin temperatures during the meat-packing work are presented in appendices to Paper II.

When assessing thermal sensations, meat-packing work expressed as mean value of thermal sensations of whole body and upper extremities was rated as neutral. Meanwhile, thermal sensations of fingers were rated as slightly cooled.

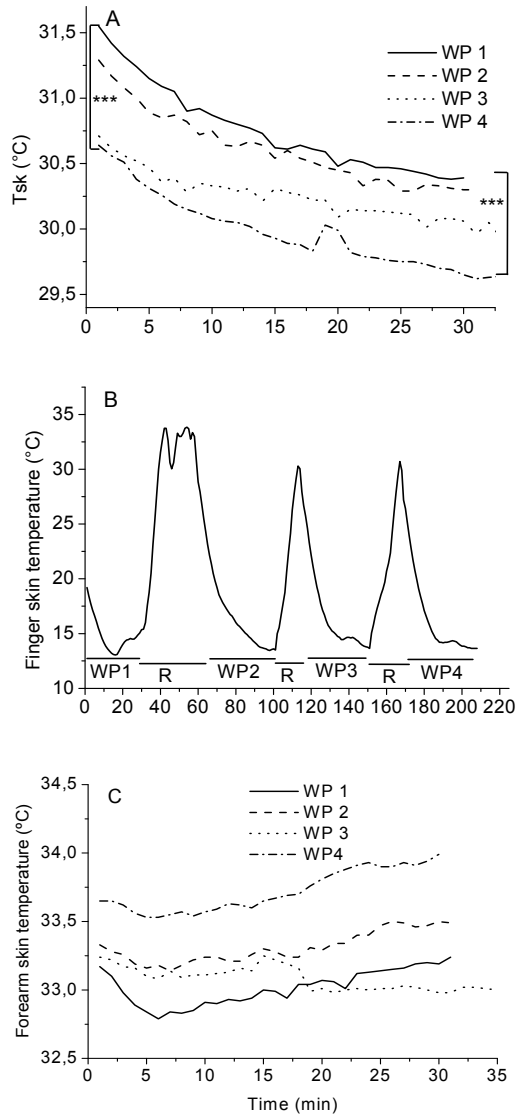


Fig. 6. T_{sk} , T_{finger} and $T_{forearm}$ above extensor digitorum muscle (right) during four consecutive work periods among female workers ($n = 18$, except in WP 4 $n = 6$) in meat-packing facilities. WP = work periods in cold conditions, R = rest period in thermoneutral conditions.

5.3.2 Effect of cold ambient temperature on thermal responses during repetitive work simulation (III)

Working in cold conditions at the ambient temperature of 4 °C for two hours decreased T_{sk} by approximately 2.7 °C ($p < 0.05$) compared with work in thermoneutral conditions, at 19 °C. At 19 °C, taking both men and women together, T_{sk} remained relatively stable during the work, whereas at 4 °C, it decreased significantly ($p < 0.001$) compared with the first, 31.8 ± 0.1 °C, and the last, 29.8 ± 0.2 °C, work period. While using the additional heating vest on the torso at 4 °C, the cooling rate in T_{sk} slowed down compared to work without the vest at 4 °C. While using the vest, T_{sk} was 32.5 ± 0.1 °C, showing a significantly higher value compared to working in the cold without the vest ($p < 0.05$, Table 3). T_{sk} was inversely associated with body fat percentage (fat %) and the correlation coefficients between T_{sk} and fat % were -0.65 ($p < 0.01$), -0.74 ($p < 0.01$) and -0.55 ($p < 0.5$), at 19 °C, 4 °C and at 4 °C with the vest, respectively (see Figure 2 in Paper III as appendix). The mean rectal temperatures did not differ significantly between the exposures.

When examining the changes in skin temperatures in different body regions, working at 4 °C decreased skin temperatures in the upper arm, the shoulder region and lower back ($p < 0.05$) compared with work at 19 °C. The most conspicuous difference between the exposures was in the fingers, being 15.6 °C lower in the cold compared with thermoneutral conditions ($p < 0.05$). The use of the vest at ambient temperature of 4 °C did not significantly change skin temperatures in the forearm compared to working at 4 °C without the vest. Mean skin temperature and local skin temperatures in the upper extremity at the exposures of 19 °C, 4 °C and 4 °C with the vest are compared in Table 3.

Gender differences in skin temperatures remained practically similar at both 19 °C and at 4 °C, and skin temperatures generally dropped to a similar extent in both genders while working at 4 °C compared to working at 19 °C. Comparing the skin temperatures in different body regions between men and women, eight out of 11 sites in upper extremity and torso were cooler in women compared to men at ambient temperature of 4 °C. Skin temperature differences between men and women were significant ($p < 0.05$) in the flexor side of the forearm (1.5 °C) and the extensor (1.5 °C) and flexor (1.1 °C) side of the upper arm. The original table for skin temperatures during the work simulations is presented in appendices to Paper III.

Table 3. Mean skin temperature (T_{sk}) and local skin temperatures in upper extremities during thermal exposures at thermoneutral (TN) temperature, cold (C) and cold with vest (CV) in women (n = 8), men (n = 8) and both genders together (“all”, n = 16). Values are mean values \pm standard error. ^ap < 0.05 in relation to the exposure at TN, ^bp < 0.05 in relation to the exposure at C, ^cp < 0.05 in relation to women.

| Site | Gender | TN (°C) | C (°C) | CV (°C) |
|---------------------|--------|-----------------------------|-------------------------------|-------------------------------|
| T_{sk} | Women | 33.1 \pm 0.1 | 30.3 \pm 0.2 ^a | 32.2 \pm 0.1 ^b |
| | Men | 33.7 \pm 0.2 ^c | 31.0 \pm 0.2 ^{a,c} | 32.9 \pm 0.2 ^{b,c} |
| | All | 33.3 \pm 0.1 | 30.6 \pm 0.2 ^a | 32.5 \pm 0.1 ^b |
| Finger | Women | 30.1 \pm 1.3 | 14.8 \pm 0.8 ^a | 19.2 \pm 1.6 ^b |
| | Men | 31.2 \pm 0.4 | 15.5 \pm 1.1 ^a | 20.0 \pm 1.7 |
| | All | 30.7 \pm 0.7 | 15.1 \pm 0.7 ^a | 19.6 \pm 1.1 ^b |
| Wrist extensors | Women | 36.1 \pm 0.2 | 34.9 \pm 0.6 | 34.4 \pm 0.5 |
| | Men | 36.2 \pm 0.2 | 35.1 \pm 0.6 | 35.0 \pm 0.5 |
| | All | 36.2 \pm 0.1 | 35.0 \pm 0.4 | 34.7 \pm 0.4 |
| Wrist flexors | Women | 34.2 \pm 0.2 | 31.9 \pm 0.3 ^a | 31.9 \pm 0.5 |
| | Men | 34.9 \pm 0.1 ^c | 33.4 \pm 0.4 ^{a,c} | 33.1 \pm 0.2 ^c |
| | All | 34.5 \pm 0.1 | 32.7 \pm 0.3 ^a | 32.5 \pm 0.3 |
| Upper arm extensors | Women | 33.5 \pm 0.2 | 30.2 \pm 0.3 ^a | 31.1 \pm 0.3 ^b |
| | Men | 34.4 \pm 0.2 ^c | 31.7 \pm 0.5 ^{a,c} | 32.1 \pm 0.4 ^c |
| | All | 33.9 \pm 0.2 | 30.9 \pm 0.3 ^a | 31.6 \pm 0.3 |
| Upper arm flexors | Women | 34.7 \pm 0.1 | 32.9 \pm 0.4 ^a | 33.3 \pm 0.3 |
| | Men | 35.4 \pm 0.2 | 34.0 \pm 0.4 ^c | 34.0 \pm 0.3 |
| | All | 35.0 \pm 0.1 | 33.4 \pm 0.3 ^a | 33.6 \pm 0.2 |

Mean values of thermal sensations in the whole body, upper extremities and fingers during the 2 hours of working at 19 °C were rated as “warm”. The sensations in the whole body and upper extremities while working at 4 °C were significantly lower (p < 0.05), being “neutral”, whereas fingers were rated as “cool”. Working with the vest maintained thermal sensations more effectively compared with work at 4 °C without the vest (p < 0.05), “warm” in whole body and upper extremities and “neutral” in fingers. Men and women reported similar thermal sensations during the work simulations.

5.3.3 Effect of intermittently increased workload on thermal responses in the cold (IV)

During 2 hours of monotonous repetitive wrist flexion-extension work at 4 °C, with the estimated thermal insulation of clothing of 0.9 clo (0.14 m² · °C/W), T_{sk} decreased from the beginning of the work by 3.7 °C during C_{work} and 4.0 °C

during I_{work} ($p < 0.05$). T_{re} decreased by 0.7 to 1.0 °C during both exposures ($p < 0.05$). There were no significant differences in T_{sk} and T_{re} between C_{work} and I_{work} .

When assessing skin temperatures in the extensor and flexor side of the forearm, no significant differences were observed between the two different exercise modes. After the 2-hour working session, skin temperature in the flexor side of the forearm was 0.7 °C and 0.5 °C higher in C_{work} and I_{work} , respectively, compared with the beginning of the work. Skin temperatures in the extensor side of the forearm decreased from the beginning of the work by 1.8 °C in C_{work} and by 2.1 °C in I_{work} ($p < 0.05$).

5.4 Neuromuscular function during repetitive work in the cold

5.4.1 Muscular strain among female workers in cold meat-packing facilities (II)

Meat-packing work, which includes repetitive hands movements, in cold meat-packing facilities loaded especially the forearm muscles, and the highest relative muscular strain, expressed as % MEMG, was seen in wrist extensors (ED). When assessing muscular strain in ED, expressed as the pooled data of both right and left upper extremity, mean values were $17.6 \pm 1.6\%$, $17.0 \pm 1.7\%$, $15.9 \pm 1.8\%$ and $18.0 \pm 2.2\%$ MEMG in the first, second, third and fourth work period, respectively. The corresponding values in the wrist flexors (FCR) varied from 8 to 12% MEMG. The workload remained relatively stable during the 3.5 hours of working and there were no consistent, statistically significant changes in muscular strain between the four working periods. The original table for muscular strain during meat-packing work is presented in appendices to Paper II.

5.4.2 Effect of cold ambient temperature on neuromuscular function during repetitive work simulation (III)

During the 2 hours of repetitive sausage-packing simulation, muscular activity remained relatively stable, without significant differences between the work periods. The results of four consecutive 30-minute work periods are presented as pooled, as mean values of all work periods. The data from both men and women together showed that working in cold conditions increased aEMG (μV) in six out

of eight muscles compared to working in thermoneutral conditions. Muscular activity in the wrist extensors and flexors increased by 15% ($p < 0.05$) and 36% (not significant), respectively, while muscular activity in the upper arm extensors and flexors was 47% and 18% higher at C compared to TN, respectively ($p < 0.05$). In the shoulder region a significant increase in muscular activity was observed in the anterior part of DE, being 12%. Muscular activity at CV and at C did not differ significantly from each other.

In general, women showed higher muscular activity in the upper extremity and the shoulder region compared with men at each thermal environment. Comparing the differences in aEMG, a significant difference between the genders was observed in only one muscle out of eight, in the shoulder region (the medial part of DE) both at 4 °C and at 19 °C, where women had 56% and 69% higher muscular activity compared to men, respectively ($p < 0.05$). When assessing % MEMG-values, gender differences were also significant in wrist extensors (ED) at 19 °C and at 4 °C with the vest, in upper arm extensors (TB) at 4 °C with the vest, in upper arm flexors (BB) at each exposure and in the shoulder region (the anterior part of DE) at 4 °C. The original table is presented in appendices to Paper III.

In spite of the finding that women generally worked at higher muscular activity compared with men, the effect of cooling on muscular activity had a tendency to be higher in men compared with women. A statistically significant increase in muscular activity in men was observed in two out of eight muscles: in the extensor sides of the forearm and upper arm (ED and TB, $p < 0.05$). In men, the highest increase in muscular activity was in the flexor side of the forearm, being 30.4 μV higher at 4 °C compared with 19 °C. However, the difference was not significant due to large inter-individual variations in the data (Figure 7).

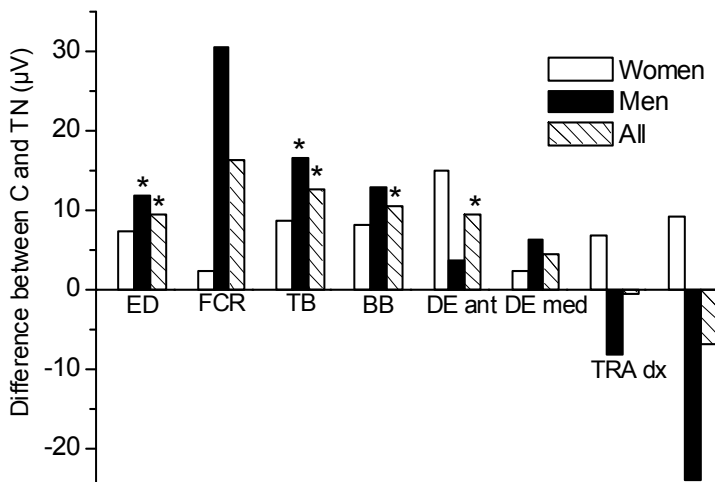


Fig. 7. Cold-induced change in muscular activity (μV) during the work simulation in women ($n = 8$), men ($n = 8$) and both genders together (“all”, $n = 16$). Values represent the mean difference in EMG activity between the exposures at C and TN. Positive values indicate that muscular activity is higher at C than at TN, while negative values indicate that muscular activity is lower at C than at TN. Abbreviations: ED = extensor digitorum muscle, FCR = flexor carpi radialis muscle, TB = triceps brachii muscle, BB = biceps brachii muscle, DE ant = the anterior part of deltoideus muscle, DE med = the medial part of deltoideus muscle, TRA = descending part of trapezius muscle, dx = right side, sin = left side. * $p < 0.05$ in relation to the exposure at TN.

Muscular activity during work simulation was inversely associated with maximal isometric strength in the extension and flexion side of the forearm at each thermal condition; however, being significant only among women at TN ($p < 0.05$, see Figure 4 in Paper III as appendix). There were significant differences in the mean values of maximal isometric strength (N) during wrist extension and flexion between men and women, and the mean values were on average 1.5-fold greater among men compared with women. At TN, maximal isometric strength in wrist flexion was 260 ± 16 N in men and 155 ± 6 N in women. The corresponding values in wrist extension were 140 ± 6 N in men and 93 ± 2 N in women. There were no significant differences in maximal isometric strength between the exposures at TN, C and CV.

For wrist extensors (ED), practically, a lack of EMG gaps was found during repetitive work at each thermal exposure, being 0.3 ± 0.0 , 0.3 ± 0.0 and 0.2 ± 0.1 gaps per minute at 19 °C, 4 °C and 4 °C with the vest, respectively. Corresponding values in the shoulder region (the medial part of DE) were 4.8 ± 1.1 , 1.7 ± 0.4 and 2.1 ± 1.7 gaps per minute. Working in cold conditions at 4 °C for two hours decreased the number of EMG gaps by 1.4 to 68.2% in seven out of eight muscles compared with thermoneutral conditions at 19 °C (see Figure 3 in Paper IV as appendix). The most pronounced decrement was found in the wrist flexors (FCR). Figure 8 shows the time course of the EMG gap behaviour of the four muscles that showed the greatest difference between thermoneutral and cold conditions.

There was a tendency for a higher number of EMG gaps in men compared with women during work at both 4 °C and 19 °C. However, the only significant differences at 4 °C were found in the upper arm flexors (BB) and in the shoulder region (the anterior part of DE) after 60 minutes of working. At 19 °C, gender differences were statistically significant in the upper arm flexors and extensors (biceps brachii and triceps brachii muscles) at 30 minutes and (triceps brachii muscle) at 120 minutes, and in the wrist flexors (flexor carpi radialis muscle) after 90 minutes of working.

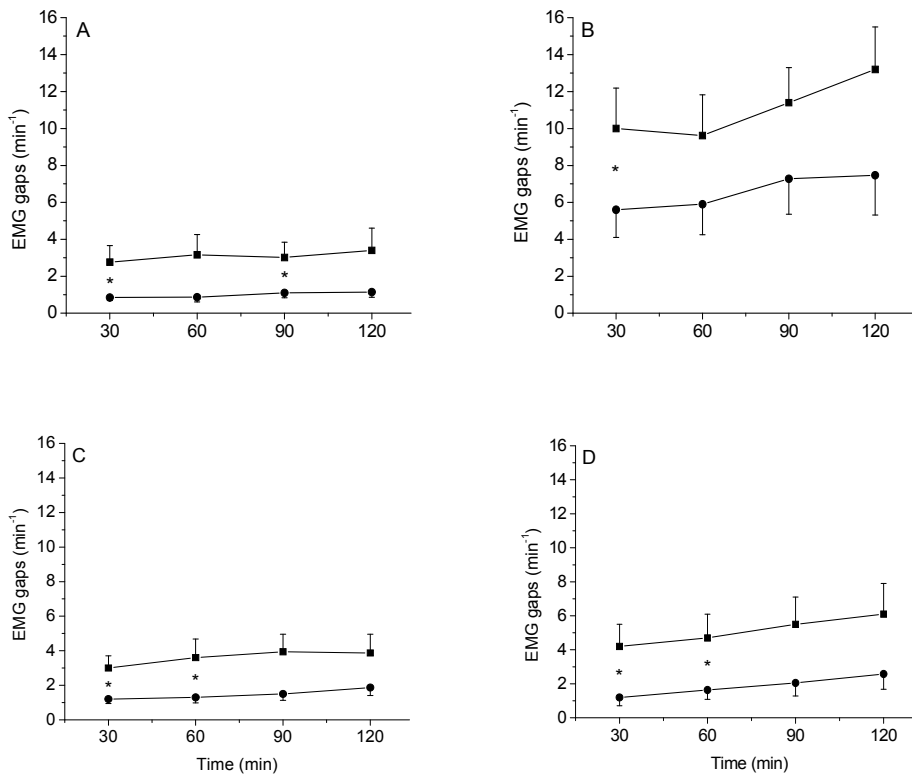


Fig. 8. Frequency of electromyographic (EMG) gaps during the work simulation study in flexor carpi radialis muscle (A), triceps brachii muscle (B), the anterior part of deltoideus muscle (C) and the medial part of deltoideus muscle (D) in thermoneutral (squares) and cold (circles) conditions. Values are for both genders together (n = 16) in each condition. * p < 0.05 between conditions

5.4.3 Effect of intermittently increased workload on neuromuscular function in the cold (IV)

When doing continuous repetitive wrist flexion-extension work, the median frequency (MF, Hz) of the wrist flexors (FCR and FDS) during the concentric phase of muscle contraction was significantly (p < 0.05) higher in intermittently increasing workload (I_{work}) compared with work without workload changes (C_{work})

after 40 minutes of working. A tendency for higher MF was also observed for the extensor muscles (B and ECR). During the eccentric phase, there was no difference between the median frequencies of the exercise modes.

In I_{work} during the concentric phase of muscle contraction, the aEMG activity of the forearm flexors had a tendency to be lower (not significantly) after 40 minutes of work compared with C_{work} . For forearm extensor there was no consistent difference between the working modes. During eccentric contraction, the situation was reversed. There were no differences between the working modes in forearm flexors, but in the extensors during I_{work} , the EMG was significantly lower after 20 to 80 minutes of work compared with C_{work} .

When comparing the different work modes, the intermittently increasing workload produced a significantly higher frequency of EMG gaps during a 2-hour session compared to the more monotonous working mode. The number of EMG gaps in the extension and flexion side of the forearm was 37% and 44% higher ($p < 0.05$) in I_{work} compared with C_{work} , respectively.

Maximal wrist flexion force decreased significantly during both working modes by 18% in C_{work} and 15% in I_{work} ($p < 0.05$). A significant drop in maximal force production occurred earlier in C_{work} (after 60 minutes of work) compared with I_{work} (after 80 minutes of work, $p < 0.05$).

5.5 Association between muscular activity and skin temperatures (II, III)

During the meat-packing work on the factory floor, at the ambient temperatures of 4 °C to 10 °C, the results indicated weak, statistically insignificant, negative correlation coefficients between increment in muscular activity (% MEMG) and decrement in skin temperature in the forearm region. In the shoulder region, no consistent and significant findings between muscular activity and skin temperature decrement were found.

During the simulated meat-packing work in laboratory conditions at 4 °C, skin temperature was inversely associated ($r = -0.85$, $p < 0.01$) with muscular activity (% MEMG) in wrist flexors (FCR) among women: a 1 °C decrease in forearm skin temperature produced an average increase of 5% in muscular activity. Working at 4 °C with the estimated thermal insulation of clothing of 1.6 clo (0.25 m²·°C/W), maintained skin temperatures at individual sites in the forearm and upper arm and the shoulder region at a fairly high level, 32 to 35 °C, 30 to 34 °C and 34 to 35 °C, respectively (see Table 1 in Paper III as appendix).

This may be the reason for inconsistent findings for the associations between skin temperatures at individual sites and muscular activity at the same sites. In addition to FCR at 4 °C, significant inverse associations were present only in the pooled data of men and women in wrist flexors (FCR, $r = -0.54$, $p < 0.05$) at 19 °C and upper arm flexors (BB, $r = -0.52$, $p < 0.05$) at 4 °C with the heating vest and among men in upper arm flexors (BB, $r = -0.72$, $p < 0.05$) at 19 °C.

6 Discussion

6.1 Factors associated with poor work ability and disadvantage in daily activities due to musculoskeletal symptoms (I)

Factors related to cold work. The present questionnaire study revealed that 11% of the respondents reported poor work ability and that disadvantage in daily activities due to pain in musculoskeletal system was most common in the neck and shoulder region, wrists and lower back. Factors associated with work in cold conditions, such as experience of draught and local skin cooling, were significantly associated with poor work ability and musculoskeletal symptoms, respectively.

There are only few studies that have revealed the relationship between work ability and cold conditions. Anttonen & Virokannas (1994) assessed cold stress in outdoor occupations using body cooling in relation to recommended temperature limits for degradation of performance by Lotens (1993). They examined body cooling as changes in mean skin temperature (T_{sk}) and concluded that work ability may be reduced, at least temporarily, because of lowered mean skin temperature during the workday. Instead, Inaba *et al.* (2005) found no significant differences in work difficulty due to the cold between female workers engaged in classification of cold storage goods and a group of female checkers and office workers in supermarkets. The present results of a cooling-related disadvantage in daily activities due to musculoskeletal symptoms confirmed previous studies concerning an increased prevalence of neck-shoulder, upper extremity, low back and leg complaints due to cooling (Aasmoe *et al.* 2008, Bang *et al.* 2005, Inaba *et al.* 2005).

Length of employment. In the present study, poor work ability associated with higher number of years working in cold conditions. In contrast to the statement that utilization of work experience is related to good work ability among ageing workers (Tuomi *et al.* 2001), more than 15 years of working in cold conditions seems to increase the risk for poor self-assessed work ability. This association should be observed in health and work ability promotion, because the number of working years was initially associated with poor work ability already after four years of working in cold conditions.

As in the studies by Chen *et al.* (1991) and Frost & Andersen (1999), disadvantage in daily activities due to musculoskeletal symptoms in the shoulder

and low back regions increased after 4 to 8 years of cumulative exposure to cold working conditions. There are also opposite findings by Aasmoe *et al.* (2008) and Chiang *et al.* (1990) showing no association between the length of cold exposure and musculoskeletal symptoms in the neck-shoulder, upper extremities and back region. In the present study, however, the experience of wrist pain was not associated with the length of work history. The prevalence of wrist pain being equally common among younger and older workers confirmed the finding of Chiang *et al.* (1990). This indicates the importance of preventive actions at an early stage of the work career especially for the incidence of wrist pain.

Along with the number of working years, there are natural age-related factors that may also explain the association between long work history and lower work ability, because in the review by van den Berg *et al.* (2009) poor work ability was associated with older age. For the prevalence of musculoskeletal symptoms older workers reported more often disadvantage in daily activities due to pain in the neck-shoulder, shoulder and low back region compared with their younger colleagues. The present results confirm the notion that preventive measurements, such as health promotion for better health status, advice as to suitable working methods, cold protective clothing and regular rest periods in warm conditions, should be targeted at all workers already in the early stages of the career in order to achieve better work ability and well-being of the musculoskeletal system.

A physically inactive lifestyle and absence from work due to health status were significantly associated with poor work ability. The follow-up studies by Seitsamo & Ilmarinen (1997) and Tuomi *et al.* (1997b) in thermoneutral conditions revealed that work ability remained good or was improved if the amount of leisure time physical activities was increased. Similarly, those whose work ability was lowered during the follow-up had decreased their physical activity. It is generally accepted that lack of leisure-time physical activity is associated with low work ability (van den Berg *et al.* 2009). It has also been shown that a physically active lifestyle is associated with better physical functioning among working population (Leino-Arjas *et al.* 2004) and better cold tolerance (Maeda *et al.* 2005). Thus, encouraging physical activity during leisure time can be considered a beneficial measure to maintain and enhance good work ability in low ambient working temperatures. Interestingly, compared with those with no physical activity, disadvantage in daily activities due to low back pain was higher among workers who exercised one to two times a week. Unfortunately, there were several factors that were not controlled for in the present analysis, such

as smoking, detailed description of the work tasks and possible rehabilitation for the existing pain) that may have an effect on the prevalence of low back pain.

Self-assessed poor work ability was associated with a longer period of absence from work due to health reasons. A similar finding was made in the study by Reiso *et al.* (2001), who indicated that work ability was assessed as lower for those with a longer duration of sickness absence compared with workers with less sickness absence. Differences in coping strategies have been associated with the frequency and duration of sickness absence (van Rhenen *et al.* 2008). In the present study, the association remains difficult to explain, but workers with more sickness absences (more than 60 days) may have developed coping strategies in order to maintain better self-assessed work ability compared with workers with fewer sickness absences (25 to 60 days). Promotion of good work ability is an important factor in the prevention of premature retirement. In an 11-year follow-up study among food industry workers, Salonen *et al.* (2003) found that poor work ability was significantly associated with early exit from work.

Gender differences. Disadvantage in daily activities due to neck-shoulder and wrist pain was significantly higher in women compared with men. The present results, in study III, about gender differences in muscular activity during repetitive work, may indicate generally higher muscular strain in women compared with men, which may partly explain the higher prevalence of musculoskeletal symptoms among women (Nordander *et al.* 2008). Gender differences in the prevalence of musculoskeletal complaints were also detected in a previous study by Nordander *et al.* (1999) in fish-processing work where the prevalence of neck, shoulder, elbow and hand complaints was almost three times higher among female workers than among males. Furthermore, Chiang *et al.* (1990) found the prevalence of nerve entrapment at the wrist (carpal tunnel syndrome, CTS) to be more common among female frozen food packers (42%) compared with their male colleagues (30%).

In their review article, Hooftman *et al.* (2004) list explanations for the gender difference in the prevalence of musculoskeletal complaints: 1. different exposure to the risk factors at work between genders, 2. females are more prone to express pain symptoms, 3. the same risk factors may have different effects depending on gender, and 4. men and women use different coping strategies in dealing with occupational stressors, and this results in different outcomes. In line with the study by Nordander *et al.* (1999), the present results support the first explanation: women in the present study were more frequently exposed to assembly line work. Their work contained more highly repetitive manual upper extremity work and

involved more static muscular strain in the shoulder region compared with men who performed more physical work with varying muscular work.

For self-assessed work ability, there was no significant difference between the genders, whereas in the study by Griefahn *et al.* (1997) women were more prone to cold sensations and health problems compared with men. Similarly, women have been shown to have more often uncomfortable and cool sensations when exposed to draught than men (Griefahn & Künemund 2001).

Association between poor work ability and musculoskeletal symptoms. The present results in cold working conditions confirm the finding by Pohjonen (2001) that poor work ability was significantly associated with increased prevalence of disadvantage in daily activities due to neck-shoulder, shoulder and low back pain. A cross-sectional study such as this does not allow for conclusions regarding the causal relationship between the risk factors and the prevalence of musculoskeletal symptoms, and it remains uncertain whether reduced work ability increases complaints of musculoskeletal symptoms or whether the relationship is reversed. Blyth *et al.* (2003) concluded that among employees suffering from chronic pain, working with pain was more common than being on sick leave due to pain symptoms. They found that on average 60% of those who worked with pain reported reduced work effectiveness.

With regard to working in the cold, the results confirm the multifactorial feature of musculoskeletal symptoms (Malchaire *et al.* 2001) and work ability (van den Berg *et al.* 2009). In addition to individual characteristics of workers, such as state of health, female gender, increasing age and physical inactivity, factors related to work in a cold environment, such as experience of draught and cooling, as well as prolonged exposure to cold, associate with poor work ability and disadvantage in daily activities due to musculoskeletal symptoms. Identification of these work environmental factors and individual risk factors is important when developing measures to preserve work ability and to reduce the prevalence of musculoskeletal symptoms among workers in cold food-processing facilities.

6.2 Thermal responses and muscular strain among female workers in cold meat-packing facilities (II)

The study showed that of the four measured muscles in the upper extremity and the shoulder region, the highest muscular strain, on average 16 to 18% MEMG during the four consecutive work periods, was in the wrist extensors, while the

corresponding value was 8 to 12% MEMG in the wrist flexors and 6 to 14% in the shoulder region. These results indicate a high strain to the musculoskeletal system in the forearm and elbow region. This could be a possible predictor of the incidence of lateral epicondylitis, the most common repetitive strain injury (Karjalainen *et al.* 2008).

The present results showed that no marked forearm cooling developed, while cooling was obvious in the shoulder region, fingers and lower extremities. Previous studies in laboratory conditions (Winkel & Jørgensen 1991, Bell 1993, Oksa *et al.* 2002) with standardized and simple muscle exercises have shown more severe tissue cooling, where the lowest skin temperatures varied from 22 to 26 °C and the corresponding values in muscle temperatures from 24 to 33 °C. In the present study, the skin temperatures in the upper extremities and the shoulder region varied from 32 to 34 °C. It can be concluded that in the present study, the cold environment did not have a substantial effect on muscular strain, as the heat production of muscular work and the thermal insulation of clothing together maintained and even increased skin temperatures in the forearms.

The association between tissue temperatures and muscular strain is bi-directional: in standardized work in cold conditions, tissue cooling has been shown to increase muscular strain (Oksa *et al.* 2002), but on the other hand, if muscular activity (and thus muscular strain) is high enough, the heat produced by muscles while working may increase skin temperatures (Rintamäki *et al.* 1992). Consequently, both high and low skin temperatures may be associated with increased muscular strain. In the present study, we assume that muscular strain in the upper extremity could mainly be related to the manual workload, since no marked thermal changes in the upper extremity were observed during the work.

The effect of muscular activity on skin temperatures was seen most prominently above the working forearm muscles, supporting the fact that dynamic muscular exercises can be used as a method for increasing tissue temperature in cold conditions (Rintamäki *et al.* 1992, Oksa *et al.* 1996). Unexpectedly, no forearm cooling was observed after the initial decrease at the beginning of the work periods. Skin temperatures in the forearms even increased both during a single work period and during consecutive work periods. However, the heat from muscular activity was not sufficient to maintain finger skin temperatures, which dropped to the mean value of 15 °C. In some subjects, the lowest finger skin temperatures at the end of the work simulation were even below 10 °C.

The results in T_{sk} indicate that whole-body cooling occurred during the work periods. The present T_{sk} values were below 31 °C, suggesting uncomfortable

thermal sensations (Lotens 1993). The main reason for decrement in T_{sk} was cooling of the lower extremities and the shoulder region. Skin temperatures above the thigh and calf muscles decreased to lower levels during consecutive work period, which is well in line with the observations by Ozaki *et al.* (2001) and Tochiara & Ohnaka (1995) from repeated exposures to cold environment. This may, in the present study, reflect the combined effect of cold exposure and inactivity in lower extremity muscles during manual work tasks. More consideration should be given to personal cold protection, such as thermal insulation of clothing and the use of platforms, in the lower extremities in particular.

In spite of decrement in T_{sk} , whole-body thermal sensations were rated as neutral. This may reflect cold habituation or adaptation because each test subject had worked for at least 6 months on the same tasks. In the present study, the insulation of the clothing was 1.6 clo (ISO 9920 2007), showing adequate or nearly adequate insulation according to IREQ calculations (ISO 11079 2007). Work clothing should protect against cooling but should not restrict body movements, because unsuitable or excessive protective clothing may increase the physical workload and cause awkward working postures (Chen *et al.* 1991).

In the Finnish food-processing industry, cold-protective clothing was improved following cold problems observed in 1997 (Rintamäki *et al.* 2000). This may also explain the fairly high skin temperatures in the upper extremities and torso during the food-packing work in cold facilities. No association between increased upper extremity muscular strain and skin cooling could be observed. Rather, muscular strain may be related to the intensity of repetitive manual work.

6.3 Effect of cold ambient temperature and work load changes on thermal responses during repetitive work (III, IV)

With normal work clothing (1.6 clo, $0.25 \text{ m}^2\text{°C/W}$), work simulation in cold conditions, at the temperature of 4 °C , decreased skin temperatures compared with similar work in thermoneutral conditions at the temperature of 19 °C . Like on the factory floor in meat-packing facilities, T_{sk} decreased below 31 °C , suggesting uncomfortable thermal sensations, during the sausage packing simulation at ambient temperature of 4 °C , whereas at 19 °C , T_{sk} was on average 33 °C , indicating thermal comfort (Lotens 1993).

The observed gender differences in skin temperatures during the work simulation were practically the same in both thermoneutral and cold conditions,

however indicating lower skin temperatures in women than in men. The higher percentage of subcutaneous fat in women was the likely reason for the lower skin temperature compared with men, as shown by LeBlanc (1954) and Baker & Daniels (1956). Other explanations for the lower skin temperatures in women may be e.g. a greater cutaneous vascular response, greater sympathetic and parasympathetic system reactivity to local skin cooling (Cankar & Finderle 2003), or lower metabolic heat production due to lower muscle mass, and decreased thermal insulation due to smaller body mass and a larger body surface-to-mass ratio (Kaciuba-Uscilko & Grucza 2001). Furthermore, Griefahn & Künemund (2001) found that women are more sensitive to draught and have more often cool and uncomfortable sensations compared with men. This preceding argumentation is, however, in contrast to the present finding of colder (not significant) thermal sensations in men compared with women. The reason for this remains difficult to explain because men generally maintained higher skin temperatures than women also during the cold exposure. Lower skin temperatures in women, which are assumed to be strongly related to the larger amount of subcutaneous fat in comparison to men (LeBlanc 1954, Baker & Daniels 1956), do not directly indicate lower muscle temperatures. As fat tissue has a high insulating property, muscles may be cooled less in those with more subcutaneous fat compared to leaner persons.

Auxiliary heating on torso prevented skin cooling in the torso, shoulder region and distal parts of upper extremities (fingers and hands), but not in the proximal parts of upper extremities (forearm and upper arm). The present results concerning fingers indicated that auxiliary heating increased finger skin temperatures by 5 °C, which, according to the data of Glitz (2005) corresponds to 50% higher finger blood perfusion while working with the additional torso heating compared with working without the vest at temperature of 4 °C. The observation that the vest increased skin temperatures in the fingers but not in the forearm suggests that the warming was not effective enough to cause marked superficial vasodilatation in the forearm. It can be assumed that in the forearm, heat exchange between arterial and venous blood takes place in deep tissue layers (Ganong 2005). At warm body temperature, like in the present study, vasodilatation of the superficial veins in hands and fingers thus evokes increasing finger skin temperatures (Brajkovic & Ducharme 2003, Parsons 2003).

In some subjects, local heating of the torso caused unpleasant warm or hot sensations or even sweating. If the vest is used on the factory floor in the food-processing industry, with the combination of a cold work environment and

varying physical workload, these unpleasant sensations may be avoided by better individual power adjustability of the vest in accordance with thermal sensations and physical exertion.

Repetitive wrist flexion-extension work while sitting in light clothing at 4 °C decreased body core temperature (T_{re}) and mean skin temperature (T_{sk}) significantly. Furthermore, skin temperatures in different body regions in the upper extremities decreased significantly during the 2 hours of working. In contrast to the work simulation study, the heat from light muscular work during repetitive wrist flexion-extension exercise was not sufficient to maintain skin temperatures above the working muscles. The discrepancy of tissue temperature changes between the work simulation study and intermittently increasing workload study may be explained by the difference in the thermal insulation of the clothing, which was 1.6 clo and 0.9 clo, respectively. However, in this study both the continuous, light repetitive work (at 10% MVC) and intermittently increased (at 10% or 30% MVC) induced statistically insignificant changes in thermal responses.

6.4 Neuromuscular function during repetitive work in the cold

6.4.1 Effect of cold ambient temperature on neuromuscular function (III)

The present results of increased EMG amplitude in the forearm and upper arm muscles during repetitive work in the cold compared with thermoneutral conditions are in agreement with the studies by Winkel & Jørgensen (1991), Bell (1993), Oksa *et al.* (2002) and Piedrahita *et al.* (2008) showing increased EMG amplitude during both dynamic and isometric muscle contractions. Moreover, repetitive manual work in cold environment has been shown to produce more fatigue in working muscles than similar work in thermoneutral conditions (Oksa *et al.* 2002).

There could be several explanations for the changes in EMG amplitude: an increment in the recruitment of motor units because of alteration of the recruitment thresholds (Yona 1997), alteration in the order of motor unit recruitment (Faulkner *et al.* 1990) and increased reflex activity (Oksa *et al.* 2002). Rome (1990) proposed a theory of “Compression of Recruitment Order” indicating that more and faster shortening motor units are recruited for

compensating diminished power output of the muscles at low temperatures compared with higher temperatures, which may increase the EMG activity. In addition, the diminution of muscle fibre conduction velocity has been found during muscle cooling (Mucke & Heuer 1989, Petrofsky & Laymon 2005), and it is stated that a slower conduction velocity may result in an increased temporal summation, thus causing enhanced EMG amplitude of the muscle contraction that follows (Winkel & Jørgensen 1991, Oksa *et al.* 2002). As a methodological factor, cooled tissue may act as a low-pass filter, decreasing the EMG activity measured from the skin (Bell 1993). In spite of this methodological feature, the EMG activity in upper extremity muscles was higher during work in cold conditions, whereas EMG activity in the shoulder region (TRA) was lower in the cold compared with thermoneutral conditions. These two factors may indicate that the changes really originated from alteration in muscular activity rather than changes in skin properties.

The results showed that in the present environmental conditions and work tasks, auxiliary heating on torso had no effect on counteracting the muscular strain. One reason for the inconsistent effects of the heating vest could be that the warming effect of the vest was mainly directed at the heated region of the upper torso and via circulation to the fingers. The heating effect on skin temperatures above the working muscles in the upper extremity was small and the benefit of the vest remained insignificant. This finding has clinical meaning, showing that increasing local thermal insulation of the forearm may be more useful under working conditions like this.

In the work simulation study, there was practically a lack of EMG gaps in the wrist extensor muscle at each thermal condition. A similar finding was made in the study by Laursen *et al.* (2001) during computer mouse tasks, where the highest levels of EMG activity in the forearm extensors was associated with the absence of EMG gaps. In the present study, in seven out of eight muscles, there was a clear reduction in the number of EMG gaps during the low-intensity repetitive work in the cold. This finding may indicate that the muscle fibres underneath the measuring electrodes remained continuously active throughout the work period. If true, then these fibres are at a higher risk of localized fatigue, which may, in the long run, induce musculoskeletal symptoms (Veiersted *et al.* 1993).

The studies by e.g. Kurppa *et al.* (1991) and Nordander *et al.* (1999) indicate a more frequent occurrence of musculoskeletal complaints and disorders in cold work than in similar work in a thermoneutral environment. If the reduction in

EMG gaps takes place in cold work in general (Piedrahita *et al.* 2008), and considering the results of Veiersted *et al.* (1993), it could be postulated that one reason for the increased occurrence of musculoskeletal complaints in the cold is the lack of variation in muscle fibre recruitment, indicated by a smaller number of EMG gaps. For further studies, this phenomenon should be taken into account, since the observed decrement occurred in T_{sk} that was only 2.7 °C lower than the corresponding value in thermoneutral conditions.

6.4.2 Effect of gender on neuromuscular function (III)

With similar work tasks, women showed higher muscular activity than men, indicated by absolute (μV) and relative (% MEMG) parameters, during both thermoneutral and cold conditions. This is in line with the studies of Karlqvist *et al.* (1998; 1999), Wahlström *et al.* (2000) and Nordander *et al.* (2008) on work involving a computer mouse in thermoneutral conditions. The explanations for gender differences have been related to lower muscular strength among women and to anthropometric variations, which could influence biomechanical loading during work (Karlqvist *et al.* 1998; 1999, Wahlström *et al.* 2000). The present results showed that isometric muscular strength was significantly greater in men compared with women, and that lower muscular strength associated with increased muscular activity during work. Moreover, there may be differences in working techniques (Karlqvist *et al.* 1999) and activation characteristics of the muscles (Anders *et al.* 2004, Larivière *et al.* 2006) between men and women.

Both the hand surface and finger contact area are larger in men than in women (Jay & Havenith 2004). Thus, it could be assumed that women have smaller hands, and a relatively larger grip size is required by women while handling artificial sausages. This may cause a deviation from optimal muscle length in women, inducing higher muscular activity in the upper extremities during manual work, which was nonetheless identical for both genders.

EMG signal is an extremely complicated signal influenced by various factors. The amplitude of motor unit action potentials is dependent on the anatomical and physiological properties of the muscle being measured and the peripheral nervous system as well as filtering properties of the tissue and the electrodes. Surface EMG amplitude decreases as a function of increasing skinfold thickness (De Luca 1997, Nordander *et al.* 2003). Thus, in the present study (study III), the actual difference in muscular activity between men and women may be even stronger because more subcutaneous fat in women may act as a low pass filter for the

surface EMG signal. Furthermore, the value of EMG frequency increases as the diameter of muscle fibre increases (De Luca 1997).

The present results showed that cooling caused a significant increase in muscular activity in the forearm and upper arm only in men, in spite of the fact that skin temperatures in the upper extremities decreased equally in both genders, or even more so in women. However, due to differences in the amount of subcutaneous fat, skin temperatures do not necessarily denote that muscle temperatures were lower in women. Cornwall (1994) showed that men are more reactive to cooling-induced changes in the rate of force production: the effect of cold on force production became significant from 15% MVC in men and 33% MVC in women. The present results agree with the observations of Cornwall (1994) and suggest that gender differences in muscular reactivity to cold are already functioning at quite a low level, 9 to 20% MEMG of muscular activity.

The present tendency for a lower frequency of EMG gaps in women may indicate that some muscle fibres are continuously activated during low load work simulation and are thereby under a higher level of muscular strain, and may be one possible explanation for the finding that women are at a higher risk for musculoskeletal symptoms and disorders than men (Nordander *et al.* 2008). Contrary to the present finding, Nordander *et al.* (2000) and Blangsted *et al.* (2003) found no gender differences in the gap frequency in the trapezius and wrist extensor muscles during office work. However, their work was performed in thermoneutral conditions.

6.4.3 Effect of intermittently increased workload of low-intensity repetitive work on neuromuscular function (IV)

The results showed that breaking the monotonous work cycle by increasing the workload intermittently increased the number of EMG gaps and EMG frequency, whereas EMG amplitude became lower and muscles were more resistant to fatigue.

The finding of an increased number of EMG gaps during the intermittent work may indicate that more variable fibre recruitment takes place, or that the same fibres underneath the measuring electrodes were not as active as they were during the more continuous monotonous work. The finding of a higher level of MF during the concentric phase of muscle contraction supports the first argumentation. This finding possibly indicates that the 30% MVC work bouts

induced the activity of fibres with a higher firing threshold; therefore “allowing” rest pauses for fibres with a lower firing threshold.

A significant difference in EMG gaps existed already at the beginning of the work, whereas, for the median frequency, the difference occurred predominantly after 20 minutes of work. It could be speculated that the number of EMG gaps is a more sensitive indicator for changes in muscle function than median frequency. According to Nordander *et al.* (2000) and Veiersted *et al.* (1993), the decreased number of EMG gaps indicates higher risk for neck-shoulder pain; the present results are encouraging in terms of the well-being of workers in cold workplaces. Changing the stereotypic activation pattern by increasing the workload can increase the number of EMG gaps. Further research is required to identify whether the use of a 30% MVC workload is an optimal alternative, or whether the same effect is induced by any change in the workload.

The results also indicate that maximal force production remained higher and with a smaller decrease during intermittently increasing work load compared with continuous work. This may indicate that the amount of fatigue was slightly less during I_{work} than during C_{work} . If this assumption is considered to be true, it seems beneficial to alter the workload intermittently to induce less fatigue in the working muscles. The physiological mechanisms inducing lower EMG amplitude in the flexor muscles during the concentric phase and in the extensor muscles during the eccentric phase remain difficult to explain. It may be that, due to supposedly enhanced recruitment of higher threshold fibres or due to the activity of fibres outside the reach of measuring electrodes, the total amount of EMG activity remains smaller and is therefore seen as lower EMG amplitude. As the thermal environment was the same and thermal responses were practically similar in both exercise modes, the explanation for the decreased EMG amplitude must be intrinsic in nature.

6.5 Methodological considerations

The major strength of this thesis is that it combines knowledge from different kinds of studies: questionnaire study and workplace measurements in food-processing industry and experimental trials in laboratory conditions. The results also offer findings that can be utilized as part of the guidelines for workplace risk and health assessment and management in occupational health care as presented in ISO 15743 (2008) and EN 1005-5 (2007).

The questionnaire study was carried out in five meat-processing factories and two dairies, with a response rate of 85%, which makes it possible to identify the general view, associated with working in cold conditions indoors and self-assessed work ability and disadvantage in daily activities due to musculoskeletal disorders. However, reliance on self-reported work environmental factors, health status and disadvantage in daily activities due to musculoskeletal symptoms during the last 12 months may be a limitation of this kind of questionnaire study. A cross-sectional study such as this does not allow for conclusions regarding the causal relationships between the explanatory and dependent variables. Rather, the results should be interpreted as associations between the measured variables. The healthy workers effect, i.e. workers exhibiting a lower rate of musculoskeletal diseases and better work ability than the general working population due to the fact that severely ill workers or those on sick leave are excluded from the respondents, should be taken into account when interpreting the results.

Most of the previous studies dealing with the effect of cold on muscular activity have been performed in laboratory conditions with standardized muscular exercises. Study II, instead, was performed in the workplace and during normal work tasks. The analysed work tasks in the meat-packing factory were representative of food-packing work; the study thus gives a relevant overview of the physical work load of repetitive work tasks in cold food-processing facilities. The data were collected during the first half of a working day, consisting of three to four work periods, depending on the department. In order to obtain a more general analysis of muscular and thermal strain, the whole working day should be measured, or samples should be taken from the beginning, middle and end of a working day. However, the problem with a study of that kind could be that the quality and amount of the products handled may vary, causing an unequal physical workload. The results of this field study are descriptive and should be interpreted as being a sample of a normal working day. By choosing assembly lines where continuous meat-product supply was guaranteed, and by collaborating with supervisors who ensure the functionality of the assembly lines, the confounding factors in this study were minimized during the measurements.

The method for assessing perceived exertion during meat-packing work by using the Borg CR-10 scale might have been a more valid scale for local muscular strain than Borg's RPE on a scale from 6 to 20 that was used in the present study (Borg 1998). Dederling *et al.* (1999) and Hummel *et al.* (2005) have found a close relationship between objectively assessed muscle fatigue, i.e. spectral changes in EMG and subjective fatigue on a Borg CR-10 scale.

In order to identify the effects of cold working conditions and different work loads on neuromuscular function, for practical hygienic and legislative reasons performing the experimental study is possible only in laboratory conditions, as in the present study III. In laboratory studies, measurements can be performed under controlled conditions. In this study, the test subjects were familiarized with the test exercises and the work simulation mode to minimize the effect of training during the actual study. The work simulation model was chosen to suit the work in the sausage-packing department in a meat-processing factory. The clothing worn and the products handled corresponded to the real work situation in the sausage-packing department. The simulation model was thus relevant for studying the effect of cold ambient temperature on muscular strain in conditions comparable with cold conditions in the food-processing factory.

In the intermittent work study, the workload of 10% MVC was chosen because it is recommended that a load of 10% MVC should not be exceeded during dynamic work lasting more than 1 hour (Jonsson 1982). Further research is required to evaluate whether the use of 30% MVC workload is an optimal alternative for the observed positive changes in neuromuscular function, or whether any workload change induces the same effect. To assess muscular strain and neuromuscular function, the parameter used in this study, the frequency of EMG gaps can be considered as a sensitive indicator for changes in muscle function and could be more commonly used in the future.

During the studies in the workplace and in the laboratory, the number of test subjects varied from 8 to 18. The small number of subjects makes generalization of the results difficult. The results can be regarded as indicative among food-processing workers like those in the present study. However, due to the nature of physical work strain measurements, the number of test subjects in the workplace and laboratory studies can be considered acceptable.

7 Summary of the findings and conclusions

The main findings of the study were:

1. Among food industry workers, self-assessed poor work ability and disadvantage in daily activities due to musculoskeletal symptoms are associated with both impaired individual health resources and work-related factors including higher number of years working in the cold and experience of draught and cooling at work. In addition, female gender associates with an increased prevalence of neck-shoulder and wrist symptoms.
2. Among female workers, food-packing work at the ambient temperatures of 4 °C to 10 °C can be regarded as thermally uncomfortable, as assessed by the T_{sk} values. Muscular strain during repetitive work is localized especially in the forearm region.
3. With identical work tasks, women generally work at higher muscular strain compared with men. However, muscular reactivity to cold seems to be higher in men compared to women during repetitive work. Significant cold-related increase in strain is observed only in men in the extensor side of forearm and upper arm. Using additional heating on torso has no affect on muscular strain of the working muscles at 4 °C.
4. Repetitive work in the cold, at the ambient temperature of 4 °C, increases upper extremity muscular strain compared to similar work at 19 °C. Breaking the monotonous work cycle by intermittently increasing the work load counteracts muscular strain and fatigue compared with the continuous, low-intensity repetitive work at 4 °C.

According to the results, there is a need for a comprehensive approach in the promotion of work ability and musculoskeletal health among food industry workers. In the area of work demands and the environment, the preventive measures should be directed at the control of work intensity, personal cold protection and the recovering periods in warm conditions. In the area of health and functional capacity, actions should be focused on the individual health resources of the workers. Preventive measures should be targeted at all workers already in the early stages of the work career. Furthermore, gender differences on both thermal and neuromuscular responses should be considered when evaluating health and work ability promotion in food industry work.

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Appendix

Table 4. Summary of studies (in chronological order) indicating the relationship between musculoskeletal disorders and cold working conditions.

| Author, year | Exposure to cold working conditions | Type of the study | Higher risk (and its CI 95%, or p-value) for musculoskeletal disorders or symptoms due to cold exposure |
|--------------------------------|---|--|---|
| Aasmoe <i>et al.</i> 2008 | Seafood-processing: "often cold at work" | Cross-sectional study, control groups: I) seafood processing workers "never cold at work" and II) administrative workers | I) Neck/shoulder: 10.5 (3.1–35.3), Wrist/hand: 7.6 (2.9–20.3), Elbow: 5.4 (1.6–17.9), Back: 11 (4.5–26.8), Leg: 8.9 (3.0–26.1) II) $p < 0.05$ for the same region as above mentioned, except the leg |
| Dovrat & Katz-Leurer 2007 | Food store work at -20°C | Control group: food store work at $+20\dots+25^{\circ}\text{C}$ | Low back: Last 12 months: 2.9 (1.3–6.7), During work: 4.8 (1.8–13.0) |
| Bang <i>et al.</i> 2005 | Seafood-processing at $+2\dots+18^{\circ}\text{C}$: "often cold at work" | Cross-sectional study, control group: seafood-processing workers "never cold at work" | Neck/shoulders: $p < 0.001$, Wrists/hands: $p < 0.001$, Back: $p < 0.001$, Legs: $p < 0.001$ |
| Inaba <i>et al.</i> 2005 | Consumer cooperative work at $+5\dots+10^{\circ}\text{C}$ | Cross-sectional study, control group: office workers at $+11\dots+21^{\circ}\text{C}$ | Lumbago: $p < 0.05$, Wrist: $p < 0.01$, Arm: $p < 0.01$ |
| Kim <i>et al.</i> 2004 | Meat and fish-processing | Control group: workers in management, secretaries and keepers | Upper extremity complaints: $p < 0.05$, CTS: $p < 0.05$ |
| Piedrahita <i>et al.</i> 2004 | Meat-processing at $+2^{\circ}\text{C}$ | Cross-sectional study, control group: meat-processing workers at $+8\dots+12^{\circ}\text{C}$. | Neck: 3.36 (1.75–6.44), Shoulder: 3.84 (1.61–9.17), Wrist/hands: 2.57 (1.28–5.14), Lower back: 2.24 (1.52–3.92) |
| Hildebrandt <i>et al.</i> 2002 | Large variety of occupations in industry, services, health care and offices | Cross-sectional, occupationally oriented study | Low-back: for draughts, wind: 1.12 (0.89–1.43), for cold: 1.09 (0.85–1.41), Neck-shoulder symptoms: for draughts, wind: 1.45 (1.14–1.83), for cold: 1.03 (0.80–1.33) |

| Author, year | Exposure to cold working conditions | Type of the study | Higher risk (and its CI 95%, or p-value) for musculoskeletal disorders or symptoms due to cold exposure |
|--|---|--|---|
| Gorsche <i>et al.</i> 1999 | Meat-packing work | Cross-sectional and follow-up study at two intervals (253 days and 401 days) | Prevalence of CTS: 21%, Incidence of CTS: 11/100 person-years (95% CI 8.3–14.7). |
| Nordander <i>et al.</i> 1999 | Fish-processing work | Cross-sectional study, control group with varied work tasks | Women: Complaints in neck/shoulder: 2.6 (1.7–3.8), elbows/hands: 4 (2.6–6.4), lower back: 2.4 (1.4–3.9) |
| Niedhammer <i>et al.</i> 1998 | Supermarket cashiers: “exposed to cold at work” | Cross-sectional study, control group: “not exposed to cold at work” | Shoulder pain, left: 1.92 (0.96–3.82) |
| Elsner <i>et al.</i> 1997 | Work in humid or cold environment | Case-control study, occupationally induced risk factors | Men: Degenerative discopathies in lumbar spine: 2.2 (1.3–3.72) |
| Griefahn <i>et al.</i> 1997 | Food-processing at 0...+15 °C | Cross-sectional study, control group from official annual statistics | Neck/shoulder: 1.30 (1.29–1.31), Back: 1.47 (1.46–1.48) Lumbago: 1.80 (1.77–1.83), Rheumatic complaints: 2.12 (2.03–2.21) |
| Krapac <i>et al.</i> 1997 | Meat-processing in unsatisfactory microclimate | Cross-sectional study, control group in satisfactory microclimate | Significantly higher percentage of fatigue and pain and extra-articular rheumatic disease such as fibromyalgia, humeroscapular periarthritis, epicondylitis |
| Pope <i>et al.</i> 1997 | Population based study: “exposure to cold working conditions” | Case-control study, control group: “not exposed to cold conditions” | Men: Shoulder pain: 6.4 (1.5–27.0) |
| Ding <i>et al.</i> 1994 (Jin <i>et al.</i> 2000) | Meat-packing at +2...–18 °C | Cross-sectional study, control group not determined | Back pain: 2.6 (0.9–8.0) |

| Author, year | Exposure to cold working conditions | Type of the study | Higher risk (and its CI 95%, or p-value) for musculoskeletal disorders or symptoms due to cold exposure |
|--|--|---|--|
| Chiang <i>et al.</i> 1993 | Fish-processing with high repetitiveness and highly forceful movements | Cross-sectional study, control group: e.g. managers and office workers doing low repetitiveness and low forceful movements of upper limbs | Shoulder pain: for repetitiveness 1.6 (1.1–2.5), for forceful movements 1.8 (1.2–2.5), CTS: for repetitiveness 1.1 (0.7–1.8), for forceful movements 1.8 (1.1–2.9) |
| Chen <i>et al.</i> 1991 | Cold store work at –5...+5 °C | Cross-sectional study, control group at normal stores +20...+30 °C | Low back: p < 0.01, Knee: p < 0.01, Shoulder: p < 0.01 |
| Kurppa <i>et al.</i> 1991 | Sausage-packing at +8...10 °C | A 31-month follow-up study, control group: sausage makers at 20 °C | Tenosynovitis or peritendinitis: 1.5 (1.0–2.2) |
| Viikari-Juntura <i>et al.</i> 1991 | Sausage-packing at +8...10 °C | Cross-sectional study, control group: supervisors and office workers in non-strenuous work | Women: Elbow pain: 1.6 (1.1–2.4) |
| Wang <i>et al.</i> 1991 (Jin <i>et al.</i> 2000) | Fish-processing at –10...–20 °C | Cross-sectional study, control group at normal temperature at +3...+10 °C | Back pain: 9.4 (2.4–37.6) |
| Chiang <i>et al.</i> 1990 | Frozen food-processing with local cold exposure of hands and high repetitiveness | Cross-sectional study, control group having little local exposure to cold and low repetitive wrist movements | CTS: 9.39 (2.37–37.19) |
| Roto & Kivi 1984 | Meat-cutting work | Cross-sectional study, control group as construction foremen | Epicondylitis: 6.4 (0.99–40.9) |

Original papers

- I Sormunen E, Remes J, Hassi J, Pienimäki T & Rintamäki H (2009) Factors associated with self-estimated work ability and musculoskeletal symptoms among male and female workers in cooled food-processing facilities. *Industrial Health* 47(3): 271–282.
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